

SURROUNDING ROCK STABILITY CALCULATION OF INVESTIGATION TUNNEL FOR POWERHOUSE

[UPPER TRISHULI-1 HEP (216MW)]

2022. 01



Power Construction Corporation of China

FOR REVIEW

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1 General

1.1 Introduction

The Investigation tunnel for Power Station is located on the left side of powerhouse with length of about 246m. The cross section is U-shape with size of 4.2m×5.6m, gradient is 7.17%, elevation of inlet and outlet is EL. 926.5m and 944.2m respectively. According to the previous geological condition and contractor's interpretation, interbedded mica schist and quartz schist are distributed along tunnel axis and are classified as Type III and Type II as per Q method from inlet to outlet, the buried depth from inlet to outlet is about 50m to 305m, averaged 200m. It is speculated that ground water is not active and some water may seep along the joint surface.

The longitudinal profile of investigation tunnel is shown in Figure 1-1. The initial proposed excavation and supports are shown in Figure 1-2.

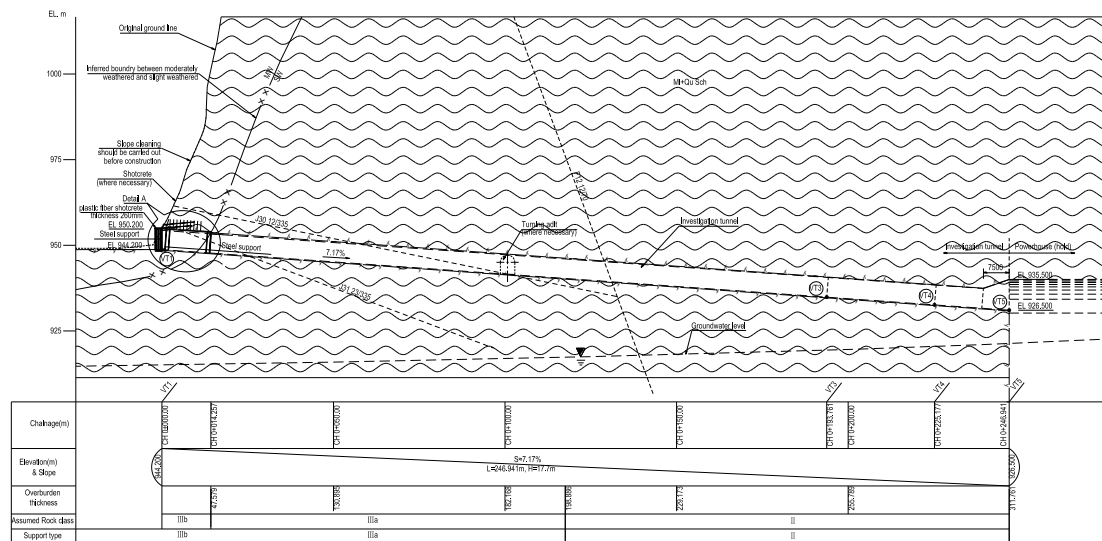


Figure 1-1 Longitudinal profile of ventilation tunnel

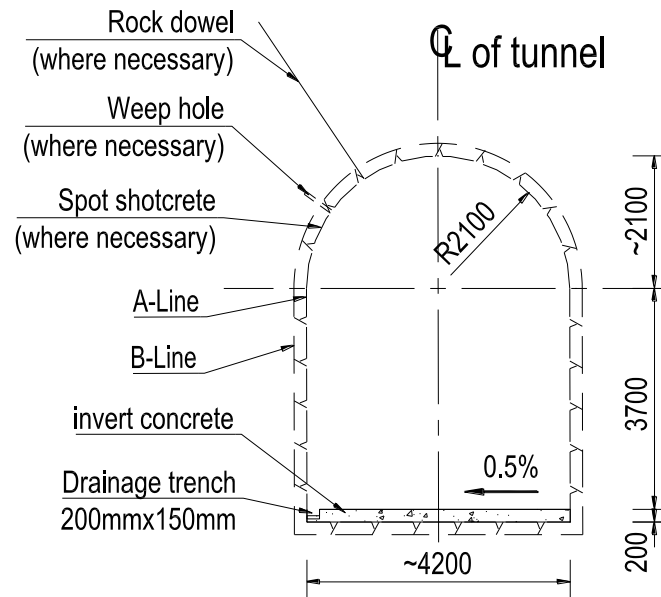


Figure 1-2 Typical section of ventilation tunnel

1.2 Design Objective

This calculation is aim to verify the proposed support measures including rock dowels, shotcrete, steel support be effective and feasible, ensure stability of tunnel and safety of construction activities during tunnel excavation.

This calculation only includes rock class I~IV, and rock class V shall be considered separately according to the actual situation.

1.3 References

- (1) Contract documents, Employer's Requirement;
- (2) Tunnels and Shafts in Rock (EM 1110-2-2901);
- (3) Building Code Requirements for Structural Concrete and Commentary (ACI 318)
- (4) Vlachopoulos, N. and Diederichs, M.S. (2009). Improved longitudinal displacement profiles for convergence-confinement analysis of deep tunnels. *Rock Mechanics and Rock Engineering*, 42(2), 131-146;
- (5) Excavation and initial support of ventilation tunnel for powerhouse (Drawing No.: UT1-C-385-CVL-DG-65002).

2 Theoretical Background of Calculations

2.1 Software

Software Phase 2 will be applied in the calculation. Phase2 is a powerful 2D finite element program for soil and rock applications. Phase2 can be used for a wide range of engineering projects including excavation design, slope stability, groundwater seepage, probabilistic analysis, consolidation, and dynamic analysis capabilities.

Software UNWEDGE is an interactive software for the stability analysis of three-dimensional wedge formed by structural discontinuity and underground excavation, which is used to analyze the underground excavation problem with discontinuous structural plane in rock mass. UNWEDGE calculates the safety factor of potentially unstable wedge, and can analyze the influence of support system on wedge stability.

2.2 Modelling Conditions, Material Law, Constitutive Model

The modelling conditions are plane strain. The material law is elasto-plastic combined with strain-softening (for rock). The rock mass is modelled as a continuum, homogeneous and isotropic. The failure criteria is the Mohr-Coulomb failure criteria. What needs to be emphasized is that such continuum model with homogeneous and isotropic material is a model, only, and does not necessarily reflect reality. In reality, the displacements occur in blocky rock masses always along discontinuities (joints, foliation etc.), which leads to loosening of the rock mass. The determined plastic zone in the continuums model represents an area of the rock mass where rock blocks were displaced to each other (= loosening of rock mass). In reality, it does not represent an area where the material was subject to plastic flow, as in soil.

2.3 Maximum unsupported span

The maximum unsupported span is calculated by the following formula as per EM 2901:

$$X = 2 \text{ ESR } Q^{0.4}$$

Where, X is maximum unsupported span, ESR is excavation support ratio, taken as 1.3. Q values and calculated and applied maximum unsupported spans are shown in Table 2-1.

Table 2-1 Maximum unsupported span of investigation tunnel excavation

Rock class	Excavation Support Ratio, ESR	Q Value	Calculated maximum unsupported span	Maximum unsupported span for application, X
I	1.3	40	11.4	11
II	1.3	25	9.4	9
III	1.3	7	5.7	5
IV	1.3	2.5	3.8	3
V	1.3	0.5	1.97	1

2.4 Calculation Methodology

As we all know, tunnel support is affected by time effect and space effect, it is not appropriate for too early or too late. Consistently, tunnel support should take full advantage of the self-stability of surrounding rock.

To determine the extent of the plastic zone and maximum displacement in the tunnel, the internal pressure reduction method is used, and 10 stages is defined in the model, relaxes an internal pressure on the tunnel boundary from a value equal to the applied in-situ stress to zero. The final stage, with zero internal pressure, will be used to determine the amount of deformation prior to support installation. The factoring of the applied internal pressure over a number of stages will be used to determine the pressure that yields the amount of tunnel wall deformation at the point of support installation. Further numerical calculation leads to loading of the support, most realistically.

The following plot was created using the Vlachopoulos and Diederichs equations (Vlachopoulos and Diederichs, 2009). Using this plot, it is possible to estimate the amount of closure prior to support installation if the plastic radius and displacement far from the tunnel face are known.

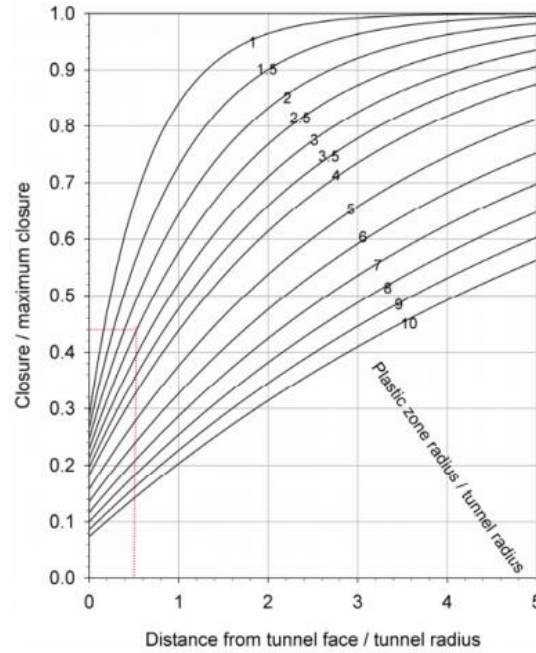


Figure 2-1 Relationship of distance from tunnel face/tunnel radius and closure/maximum closure

The equations can also be found in the Kersten Lecture, appendix 1 (Hoek et. al., 2008).

According to the formula listed in geological rock classification and documentation “Integration of geotechnical and structural design in tunneling (Hoek, E., Carranza-Torres, C., Diederichs, M.S. and Corkum, 2008)”. The calculation formula of supporting time is as follow:

$$\frac{u_0}{u_{\max}} = \frac{1}{3} e^{-0.15 P_r}$$

$$P_r = R_p / R_t$$

$$d_t = \frac{X}{R_t}$$

$$\frac{u}{u_{\max}} = \begin{cases} \frac{u_0}{u_{\max}} e^{d_t} & \text{when } X < 0 \\ 1 - \left(1 - \frac{u_0}{u_{\max}}\right) e^{\frac{-3d_t}{2P_r}} & \text{when } X > 0 \end{cases}$$

Where,

R_p —The maximum plastic zone depth, m;

u_0 —The radial displacement of tunnel face, m;

R_t —Tunnel radius, m;

X —Distance from the initial support to the tunnel face, m;

u_{max} —The maximum radial displacement, m.

Table 2-2 Relaxation of rock mass

Rock Class	X (m)	R_p (m)	U_{max} (m)	$\frac{u}{u_{max}}$	Relaxation (%)
I	11	3.62	0.8	0.99	95
II	9	4.29	2.3	0.97	95
III	5	6.29	11.7	0.77	90
IV	3	11.42	38.8	0.46	85

Relaxation refer to that (100-Relaxation)% of surrounding rock stress is borne by rock and support, Relaxation% release during excavation.

3 Properties of Materials

3.1 Rock Mass Properties

The mechanical parameters of surrounding rock are shown in Table 3-1 as per approval letter RN 0031.

Table 3-1 Mechanical parameter for surrounding rock of Investigation tunnel

Class of surrounding rock	Unit weight	Uniaxial compressive strength (UCS) of intact rock	Elastic modulus Of rock mass	Poisson's ratio of rock mass	Rock mass/rock mass shear (shearing) strength				Uniaxial compressive strength of rock mass, (UCS)	Tensile Strength of rock mass
					Peak		Residual			
	γ (kN/m ³)	σ_c (MPa)	E_m (GPa)	μ	Φ_{peak} ($^{\circ}$)	C_{peak} (MPa)	Φ_{res} ($^{\circ}$)	C_{res} (MPa)	σ_{cm} (MPa)	σ_{tm} (MPa)
I	27.0	60	30.0	0.20	50	5.0	40	3.33	27.5	2.75
II	27.0	60	20.5	0.25	48	2.5	38	1.67	13.0	1.3
III	26.5	60	7.5	0.27	43	0.9	34	0.60	4.2	0.42

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IV	26.0	60	2.3	0.30	35	0.5	28	0.33	1.9	0.19
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Note: $\Phi_{res} \approx 80\%$ of Φ_{peak} ;

$$C_{res} \approx 2/3 C_{peak};$$

$$\sigma_{cm} = 2C_{peak} \cos \Phi_{peak} / (1 - \sin \Phi_{peak});$$

$$\sigma_{tm} \approx 10\% \sigma_{cm}.$$

3.2 Rock Dowels

- 1) Dowel type: cement mortar full length bonded dowel
- 2) Yield strength: 500MPa
- 3) Compressive/ Tensile strength: 545MPa
- 4) Elastic modulus: 210000MPa
- 5) Allowable tensile strength of rock bolt steel: 500MPa/1.5=333MPa. The value 1.5 is safety factor.

3.3 Shotcrete

The mechanical parameters of shotcrete is shown in Table 3-2. Elastic modulus is calculated by formula $E_c = 4700 \cdot f_c'^{0.5}$ (ACI 318, section 19.2.2 Modulus of elasticity).

Table 3-2 Mechanical parameter for shotcrete

Compressive strength f_c' (MPa)	Tensile Strength (MPa)	Elastic modulus E_c (MPa)	Unit Weight (kN/m ³)	Poisson ratio
21	2.1	21538	24.0	0.2
30	3.0	25743	24.0	0.2

3.4 Lattice girder

The mechanical parameters of Lattice girder is shown in Table 3-3.

Table 3-3 Mechanical parameter for reinforcement steel bar

Yield strength (MPa)	Tension strength (MPa)	Elastic modulus (MPa)	Poisson ratio
500	545	210000	0.3

3.5 Steel support

MB150 H-beam from is used. The mechanical parameters of steel support (rib) is shown in

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Table 3-4.

Table 3-4 Mechanical parameter for steel support

Yield strength (MPa)	Tension strength (MPa)	Elastic modulus (MPa)	Poisson ratio
250	400	210000	0.3

4 Initial Proposed Tunnel Supports

4.1 Tunnel Support of Excavation Class

The initial proposed supports for each rock type are shown in Table 4-1.

Table 4-1 Initial proposed supports for each rock type

Item	Unit	Initial proposed supports			
		I	II	III	IV
Shotcrete thickness	mm	Spot	50	80	100
Shotcrete strength	MPa	21	21	21	21
Rock dowel length	m	3.0	3.0	3.0	3.0
Rock dowel spacing within each row	m	spot	spot	2.0	1.5
Rock dowel row spacing	m	spot	spot	2.0	1.5
Steel support/Lattice girder spacing	m				spot

4.2 Safety Factor

The support safety factor for shotcrete and rock dowel is 1.5.

The minimum safety factor for wedges analysis is 2.0.

5 Model Set-up, Boundary and Loading Conditions, Stress Initiation

For simplicity, the model will not extend to the ground surface, and the boundary of model is set 10 times tunnel width/height, but to apply corresponding stresses at the model's upper boundary.

For the case of gravitational loading, only, boundary and loading conditions to be set as shown below. This applies for tunnels in the UT1-Project that are oriented NNE-SSW (+/-

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45 °), as NE-SSW is generally orientation of the maximum horizontal stress σ_H in the Upper Himalaya, which is in the plane-strain Phase2-model the (“irrelevant”) out-of-plane stress. Hence, initial stress conditions in the model can be calculated by gravitational loading, or by specifying the relative ground surface elevation.

The finite element model for rock class I, II, III, IV, V is shown as Figure 5-1, and the corresponding gravitational loading is shown in the Table 5-1.

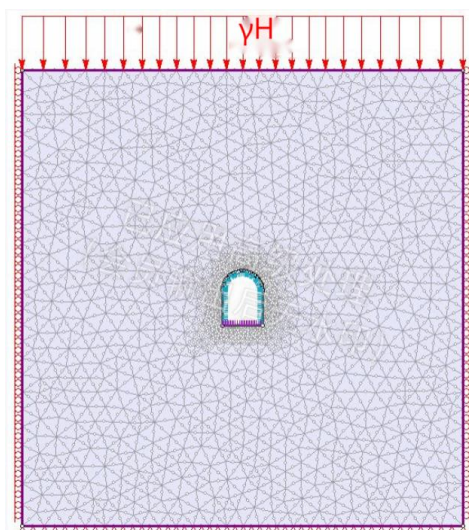


Figure 5-1 Finite element model and gravitational loading

Table 5-1 gravitational loading for surrounding rock

Rock class	Tunnel buried depth	Rock unit weight	Overburden gravitational loading	Application location of Max. buried depth
	m	kN/m ³	MPa	
I	305	27	8.24	Refer to rock class II
II	305	27	8.24	Whole tunnel
III	305	26.5	8.08	Whole tunnel
	200	26.5	5.30	Tunnel section of assumed rock class III
IV	200	26	5.20	Refer to rock class III
	150	26	3.60	Intermediate value
	100	26	2.40	Tunnel section of assumed rock class IV
	55	26	1.43	tunnel inlet

6 Tunnel Modelling and Results

6.1 Rock class I (Max. buried depth 305m)

For rock class I without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-1.

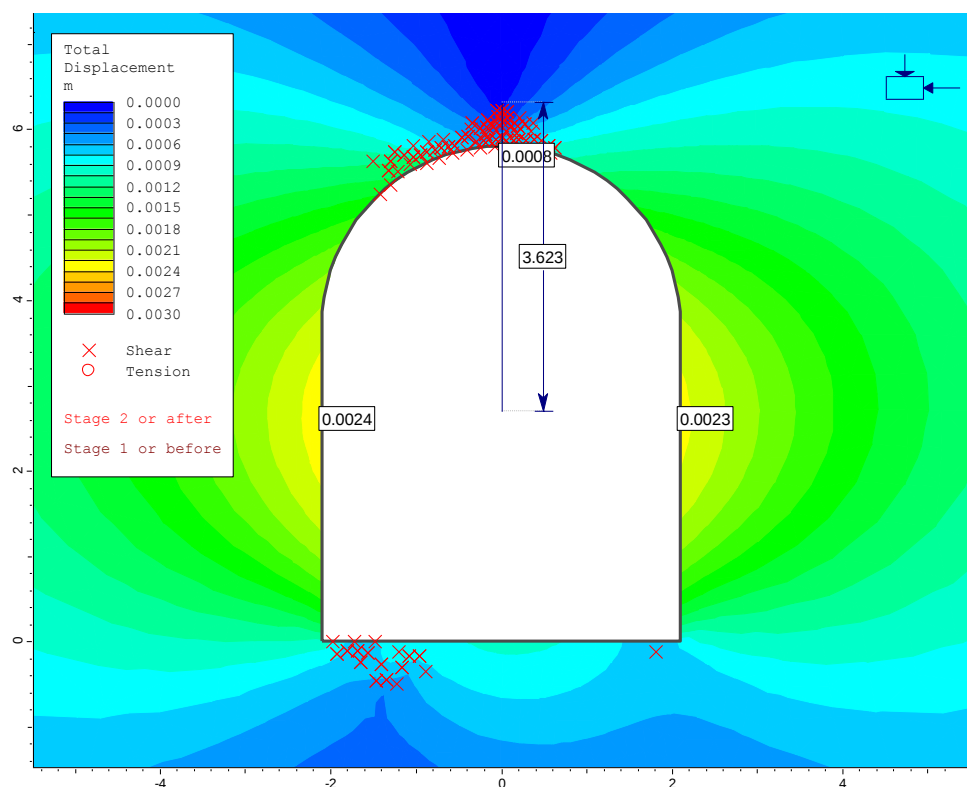


Figure 6-1 Plastic zone and total displacement (Rock Class I)

It can be seen that the maximum displacement is 0.0008m, and almost no plastic zone. In terms of stability, the systematic support is not required.

As can be seen from section 3, the lateral pressure coefficient applied is 1.5, which is too high for very good surrounding rock. Refer to EM2901, for rock class I, the lateral pressure coefficient of 1 is large enough.

While the lateral pressure coefficient is 1, the plastic zone and total displacement with support is shown in Figure 6-2.

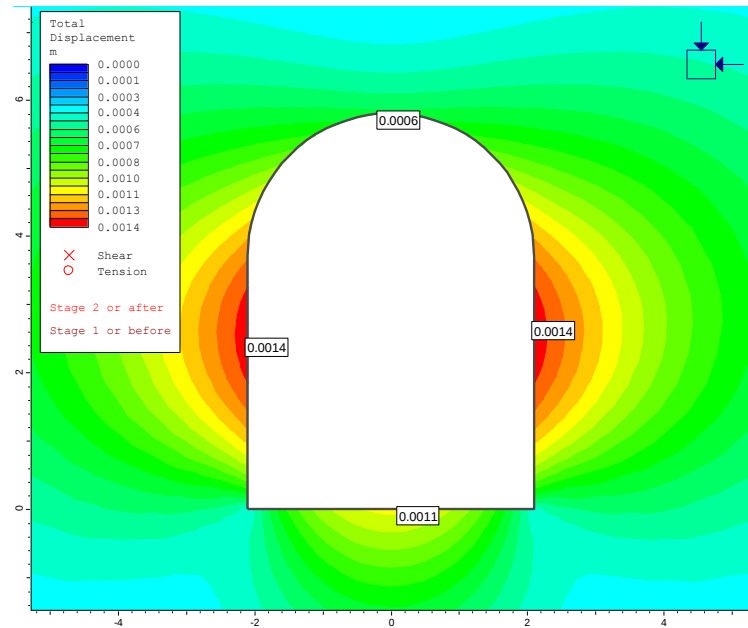


Figure 6-2 Plastic zone and total displacement (Rock Class I)

It can be seen that the maximum displacement is 0.0006m, and no plastic zone, the results are more reasonable.

6.2 Rock class II (Max. buried depth 305m)

For rock class II without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-3.

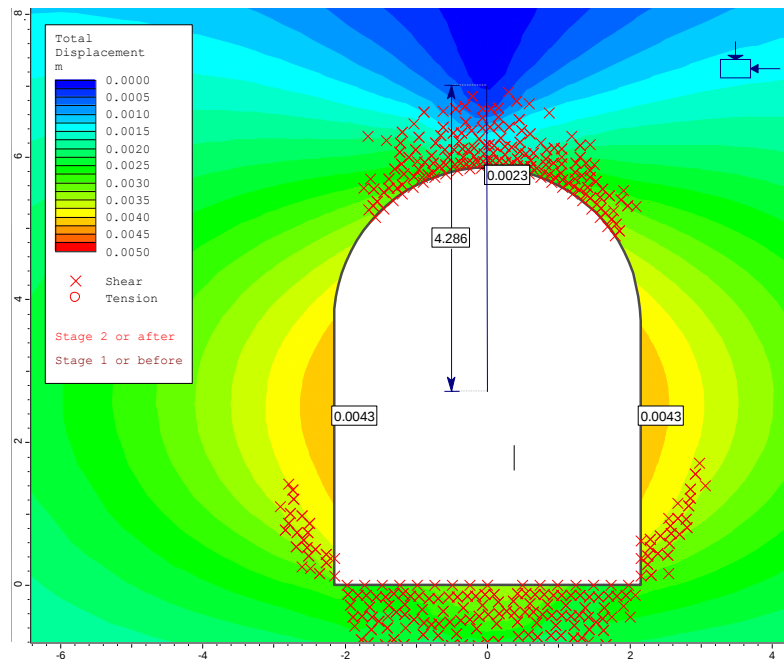


Figure 6-3 Plastic zone and total displacement (Rock Class II)

The plastic zone and total displacement with support is shown in Figure 6-4, and the bearing capacity of shotcrete is shown in Figure 6-5, and the bearing capacity of rock dowel is shown in Figure 6-6.

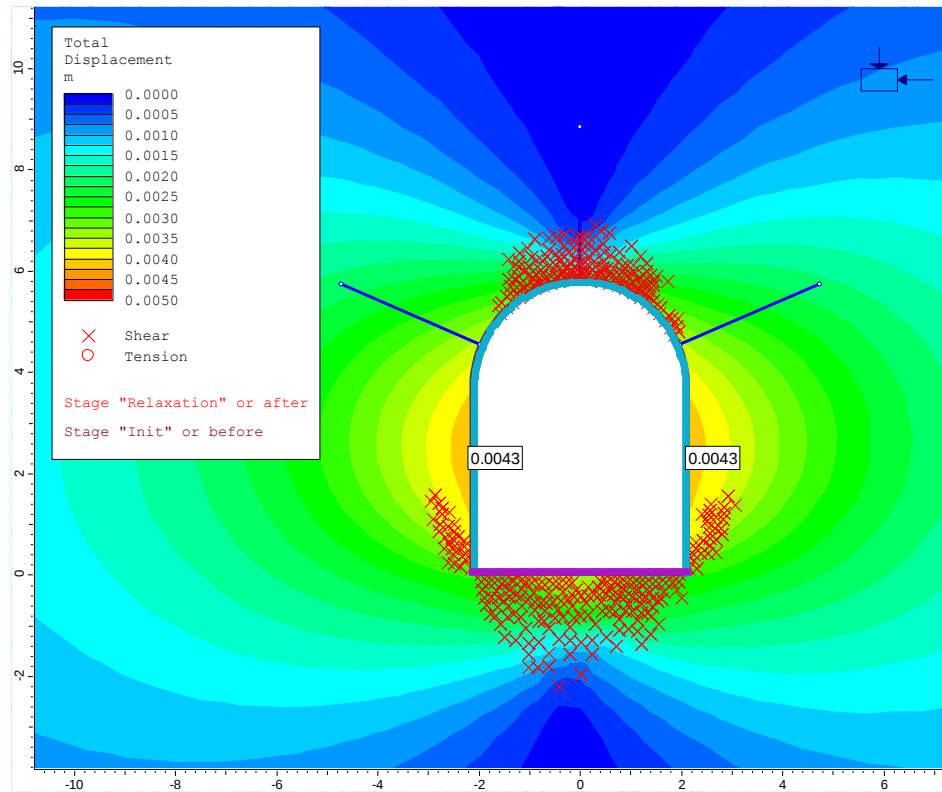


Figure 6-4 Plastic zone and total displacement with support (Rock Class II)

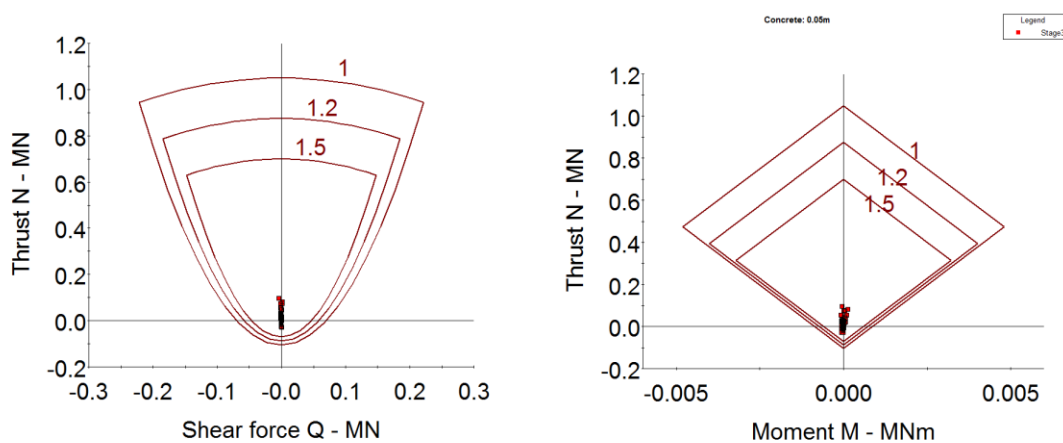


Figure 6-5 Bearing capacity of shotcrete of Ventilation tunnel (Rock Class II)

Notice that all the data points fall within the factor of safety=1.5 envelope, on all plots. This means that the support system chosen has a factor of safety greater than 1.5.

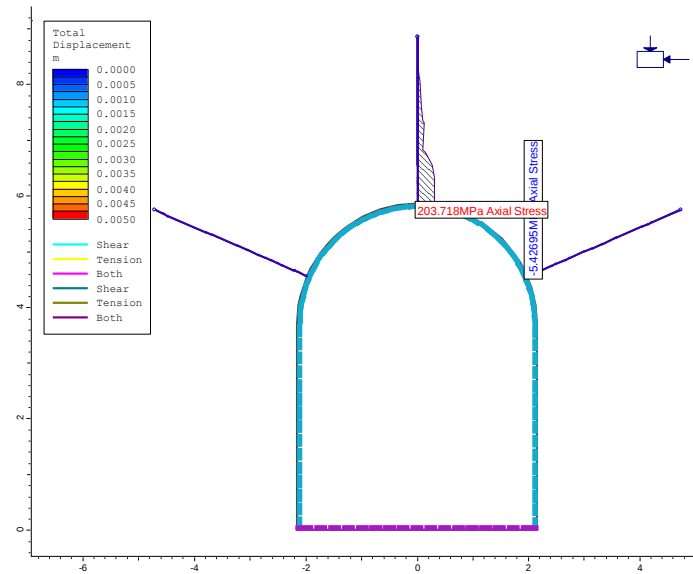


Figure 6-6 Rock dowel stress (Class II)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel.

6.3 Rock class III (Max. buried depth 305m)

For rock class III without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-7.

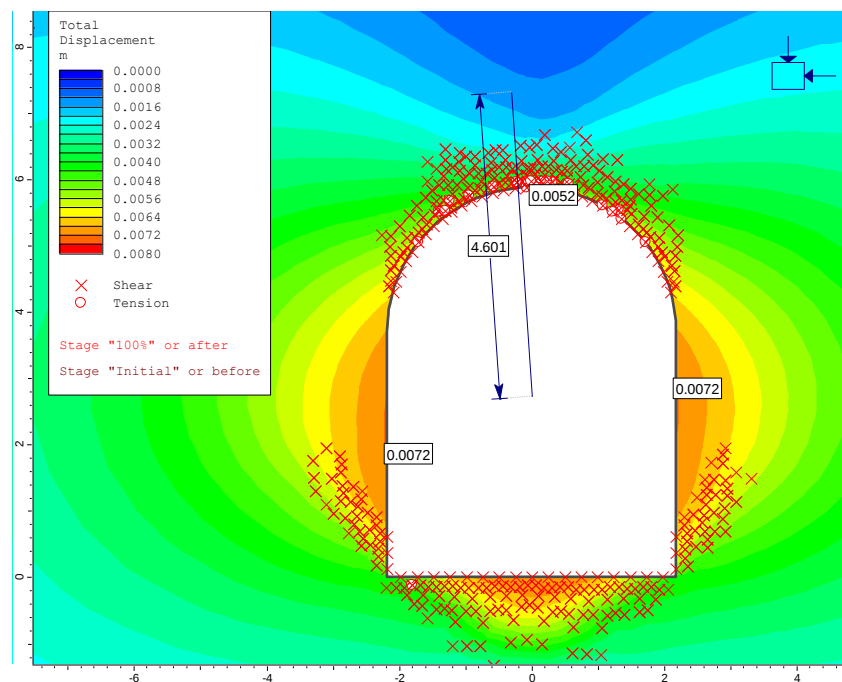


Figure 6-7 Plastic zone and total displacement (Rock Class III)

The plastic zone and total displacement with support is shown in Figure 6-8, and the bearing capacity of shotcrete is shown in Figure 6-9, and the axis stress of rock dowel is shown in Figure 6-10.

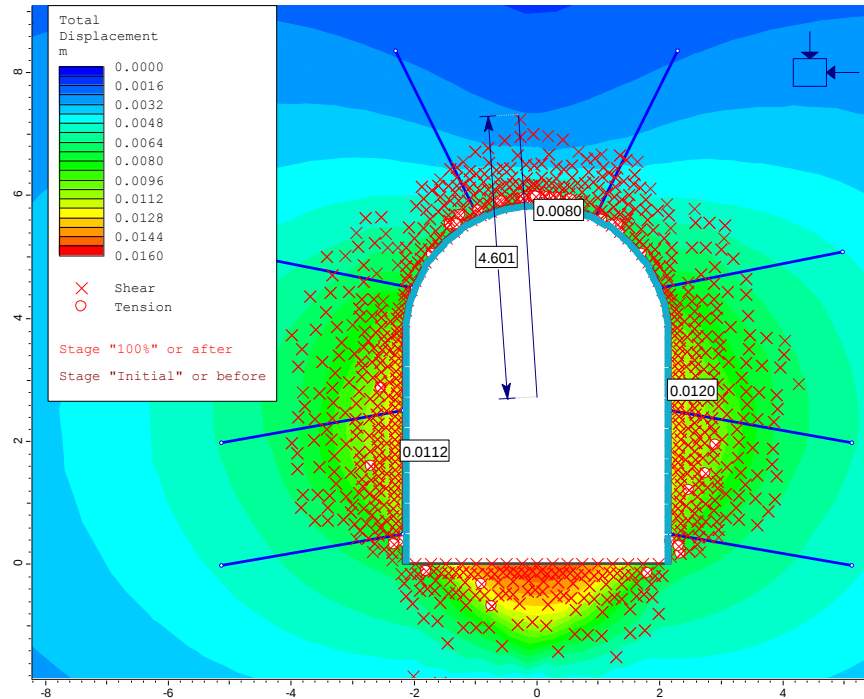
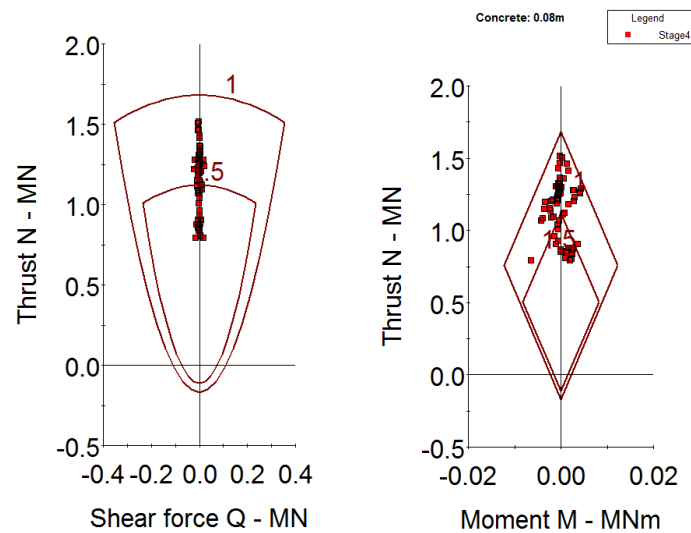


Figure 6-8 Plastic zone and total displacement with support (Rock Class III)



Support Element: plastic fiber shotcrete

Figure 6-9 Bearing capacity of shotcrete (Rock Class III)

Notice that lots of data points don't fall within the factor of safety=1.5 envelope on all plots.

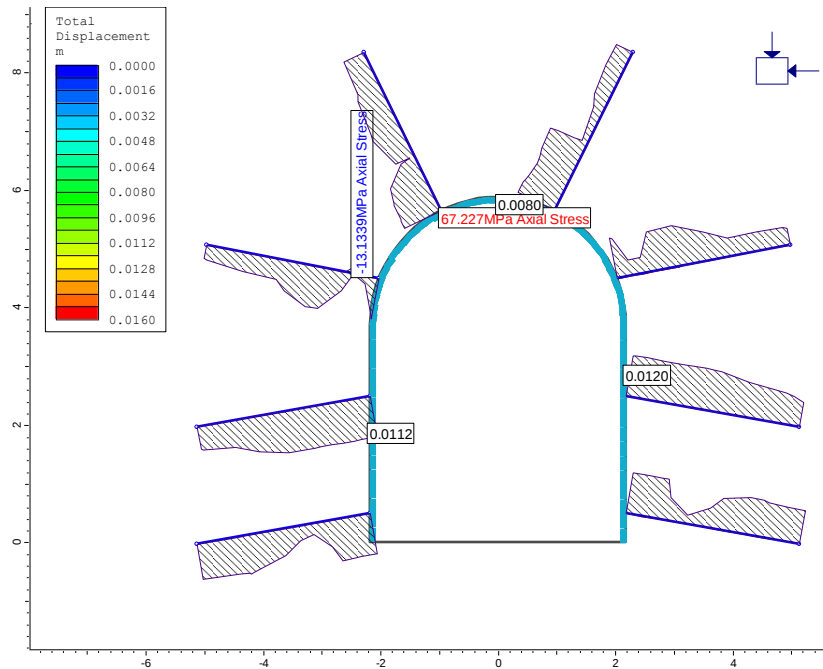


Figure 6-10 Rock dowel axis stress (Class III)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel steel.

It can be seen that for rock class III, when the thickness of the overburden rock is 305m, the plastic zone is large, and the thickness of shotcrete in section 4 of 80mm can't meet the safety requirements.

When the thickness of shotcrete is improved to 120mm, the plastic zone and total displacement with support is shown in Figure 6-11, and the bearing capacity of shotcrete is shown in Figure 6-12.

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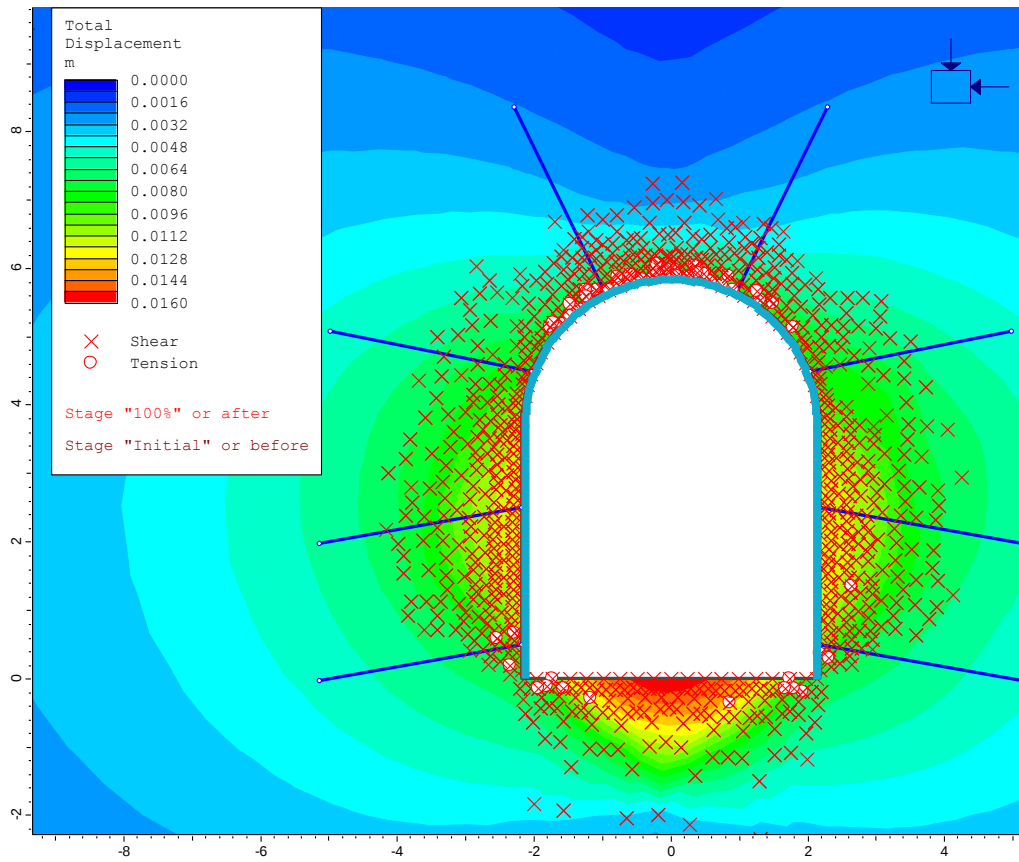


Figure 6-11 Plastic zone and total displacement with support (Rock Class III)

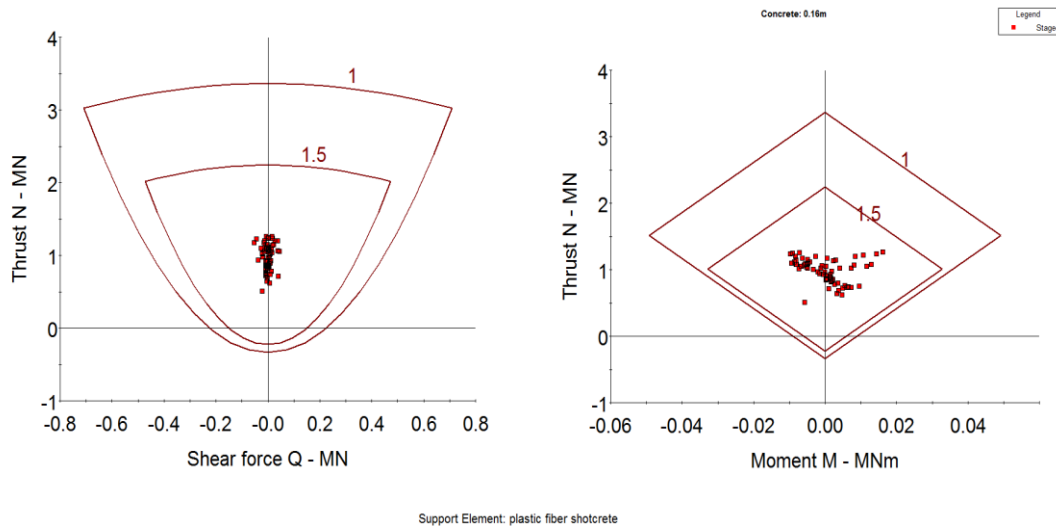


Figure 6-12 Bearing capacity of shotcrete (Rock Class III)

From above calculation results, almost all data points fall within the factor of safety=1.5 envelope on all plots.

6.4 Rock class III (Max. buried depth 200m)

For rock class III without support, adopting the parameters listed in Section 3, the results from stage 10 are used, and the calculated displacement and plastic zone are shown in the Figure 6-13.

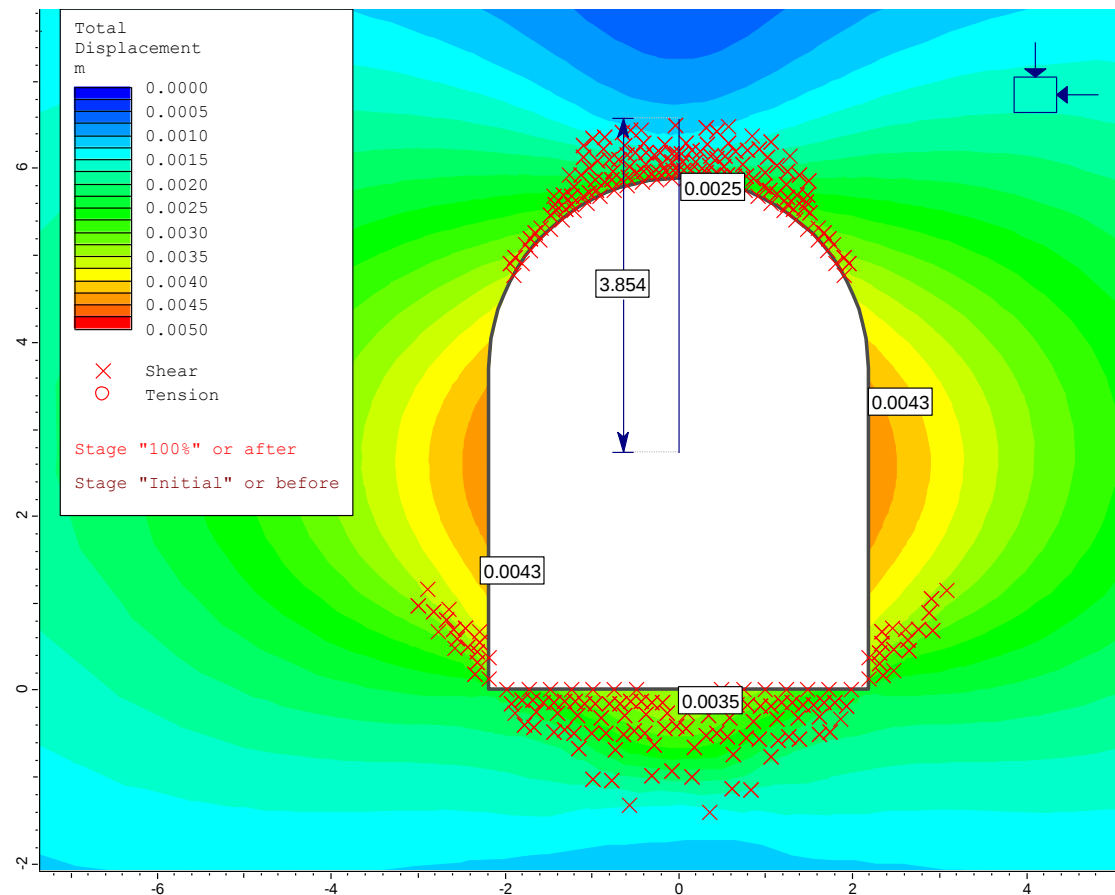


Figure 6-13 Plastic zone and total displacement (Rock Class III)

The plastic zone and total displacement with support is shown in Figure 6-14, and the bearing capacity of shotcrete is shown in Figure 6-15, and the axis stress of rock dowel is shown in Figure 6-16.

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

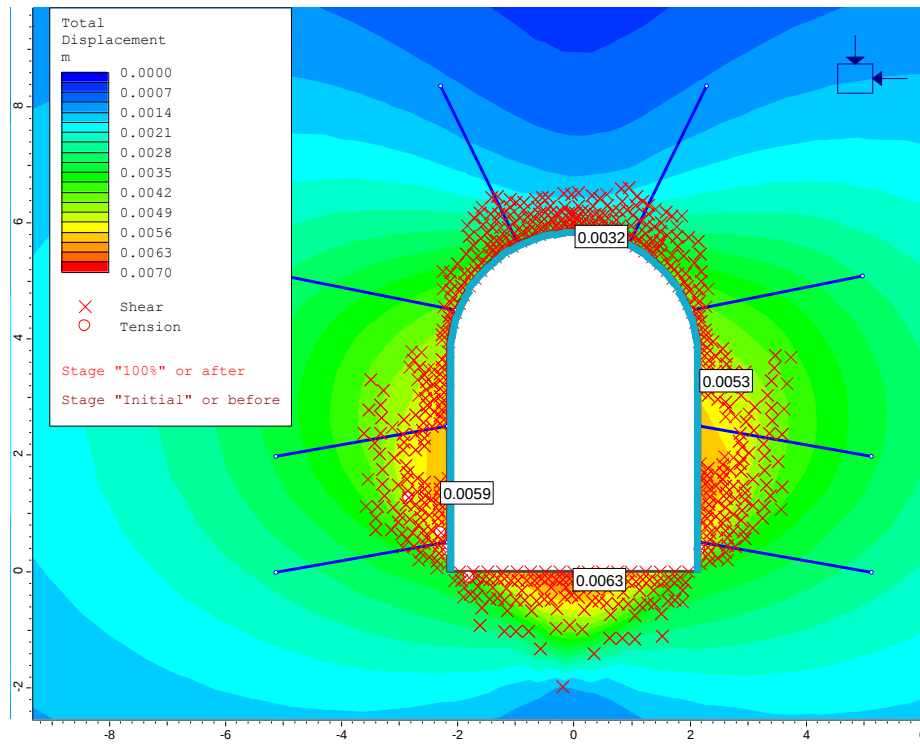
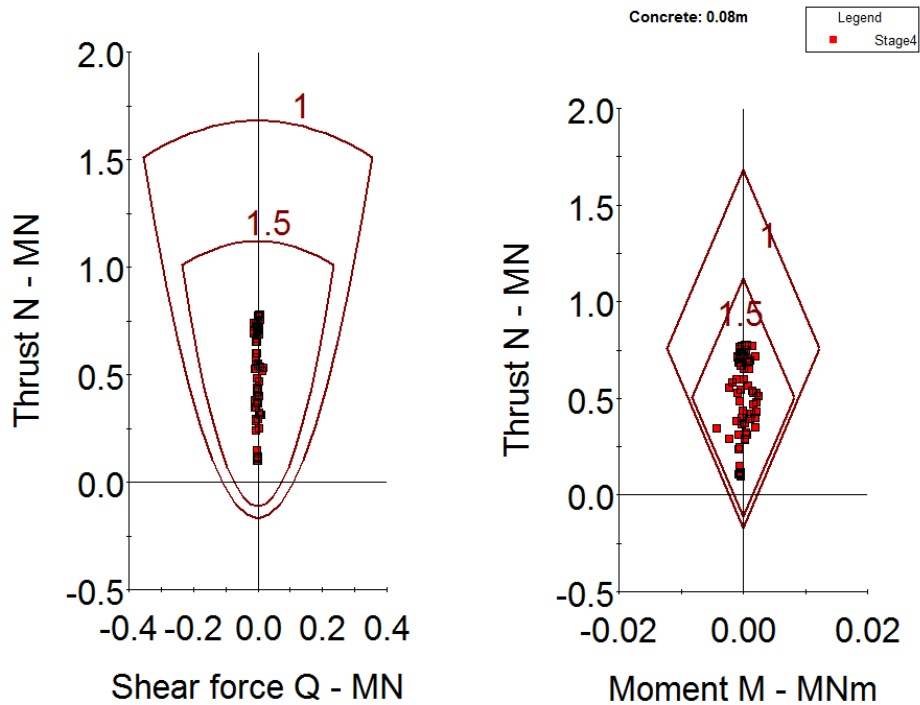


Figure 6-14 Plastic zone and total displacement with support (Rock Class III)



Support Element: plastic fiber shotcrete

Figure 6-15 Bearing capacity of shotcrete (Rock Class III)

Notice that all the data points fall within the factor of safety=1.5 envelope on all plots. This means that the support system chosen has a factor of safety greater than 1.5.

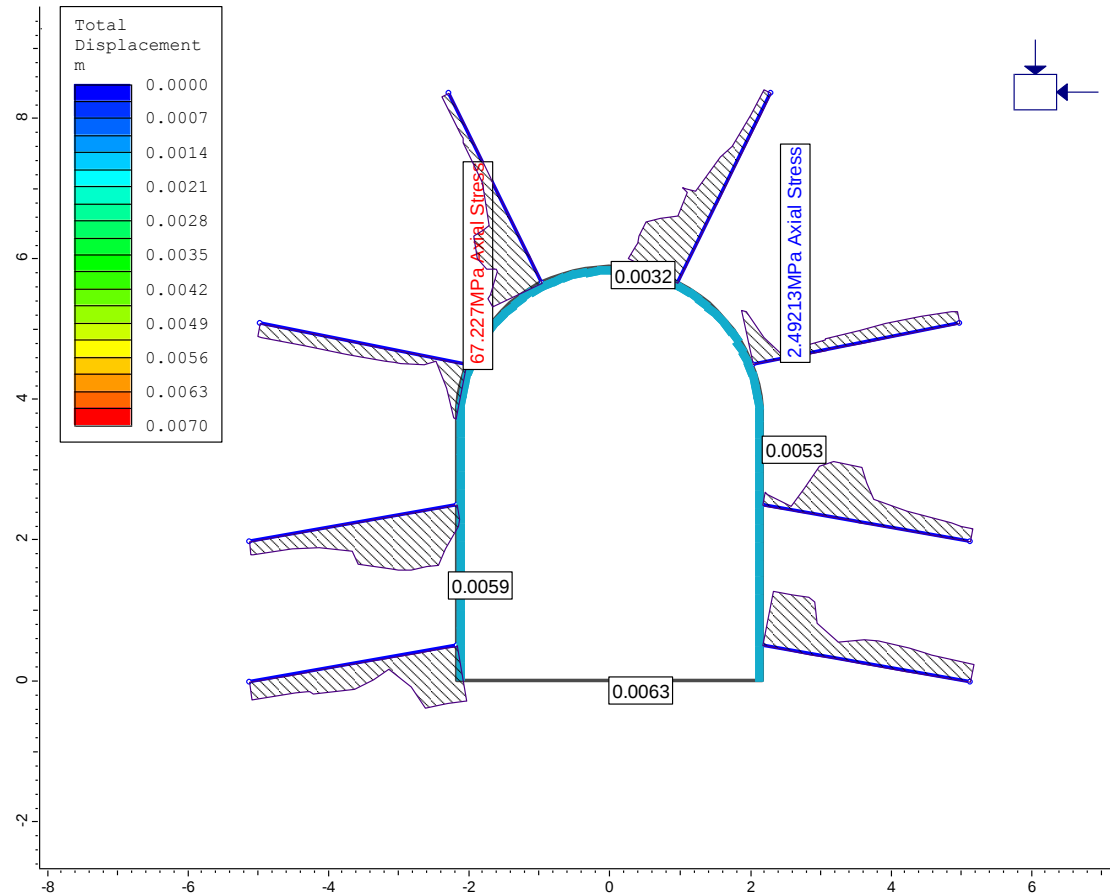


Figure 6-16 Rock dowel axis stress (Rock Class III)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel.

6.5 Rock class IV (Max. buried depth 200m)

For rock class IV without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-17.

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

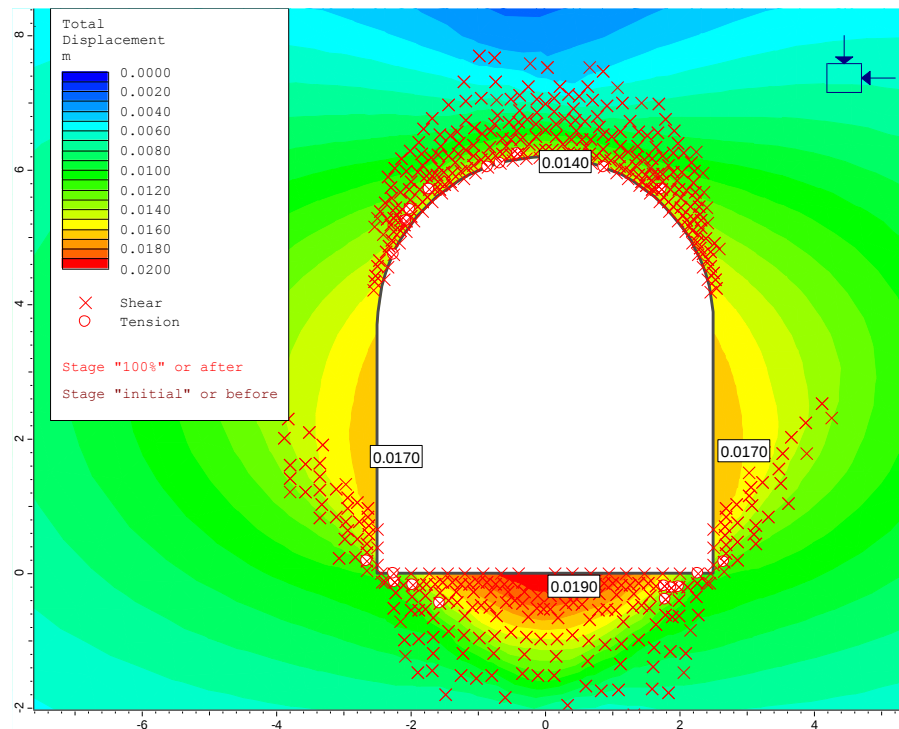


Figure 6-17 Plastic zone and total displacement (Rock Class IV)

The plastic zone and total displacement with support is shown in Figure 6-18, and the bearing capacity of shotcrete is shown in Figure 6-19.

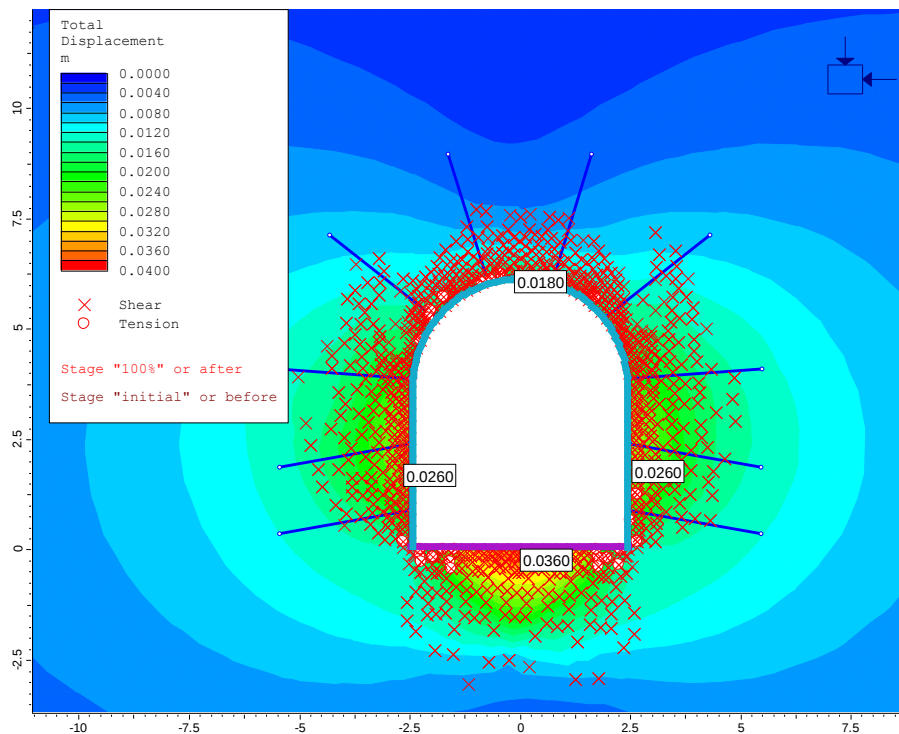
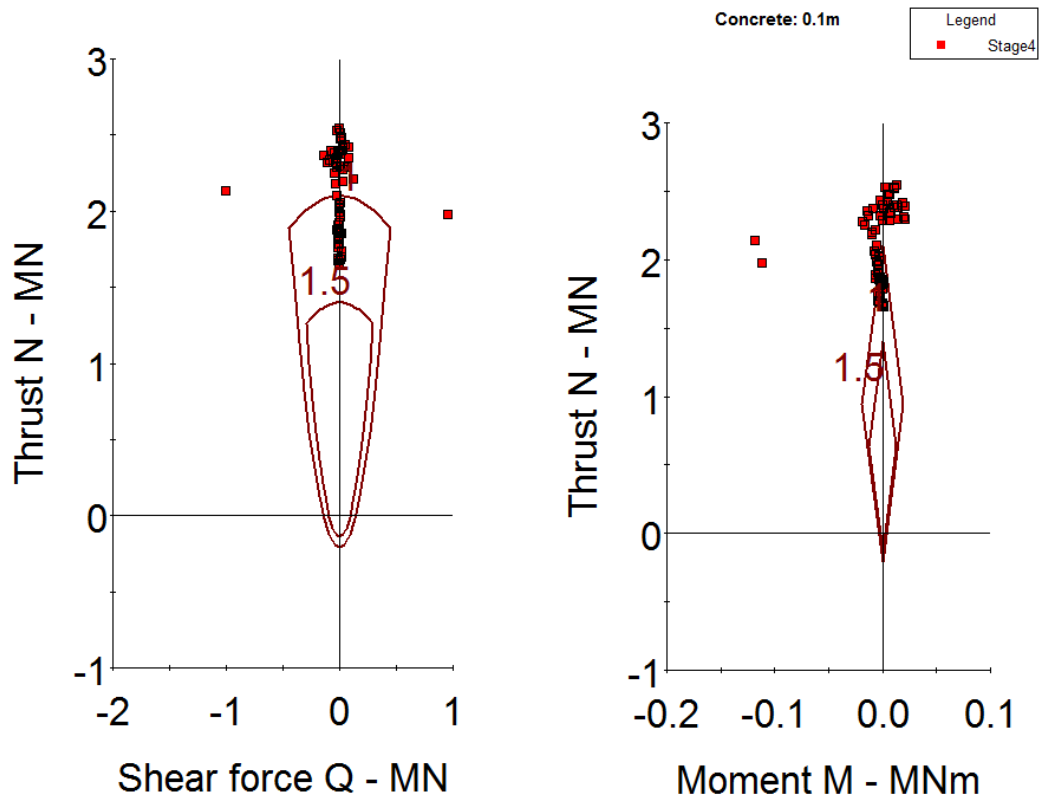


Figure 6-18 Plastic zone and total displacement with support (Rock Class IV)



Support Element: plastic fiber shotcrete

Figure 6-19 Bearing capacity of shotcrete (Rock Class IV)

Notice that lots of the data points fall out of the factor of safety=1.5 envelope on all plots.

Some support system is considered:

- (1) The shotcrete thickness is increased to 0.16m,
- (2) The shotcrete strength is increased to 30MPa,
- (3) The spacing of Steel support is increased to 1m,
- (4) The spacing of rock dowel is increased to 1m,

The plastic zone and total displacement with support is shown in Figure 6-20, and the bearing capacity of shotcrete is shown in Figure 6-21, and the axis stress of rock dowel is shown in Figure 6-22.

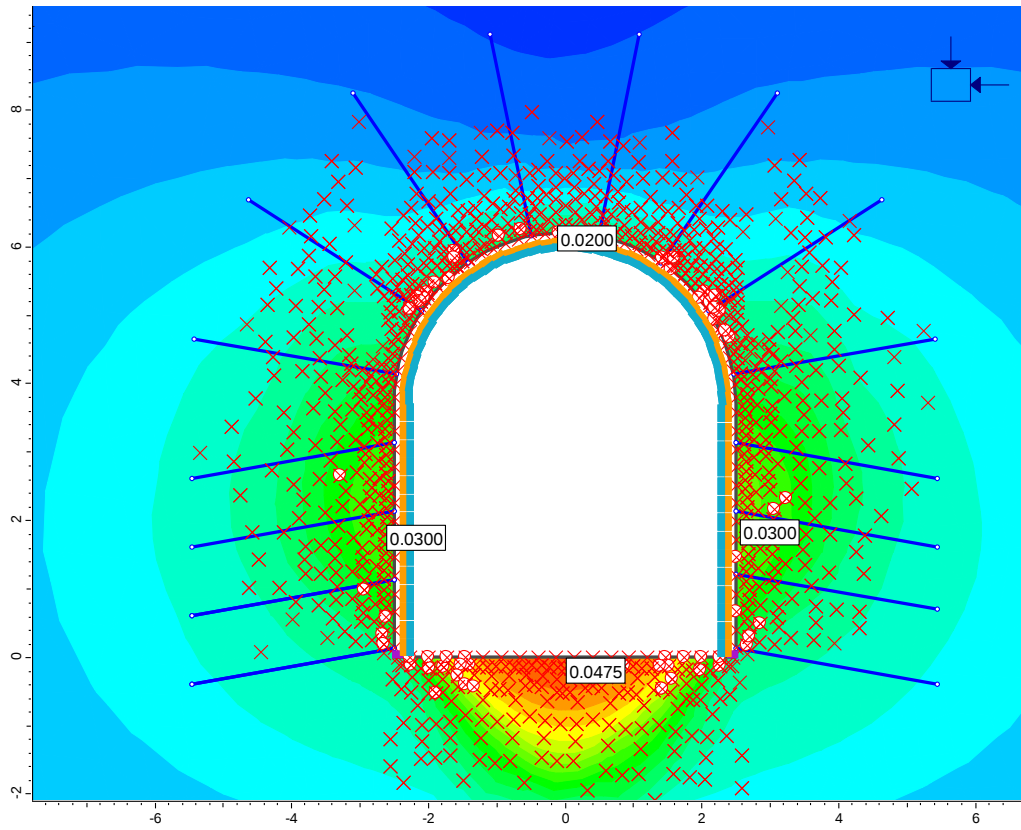
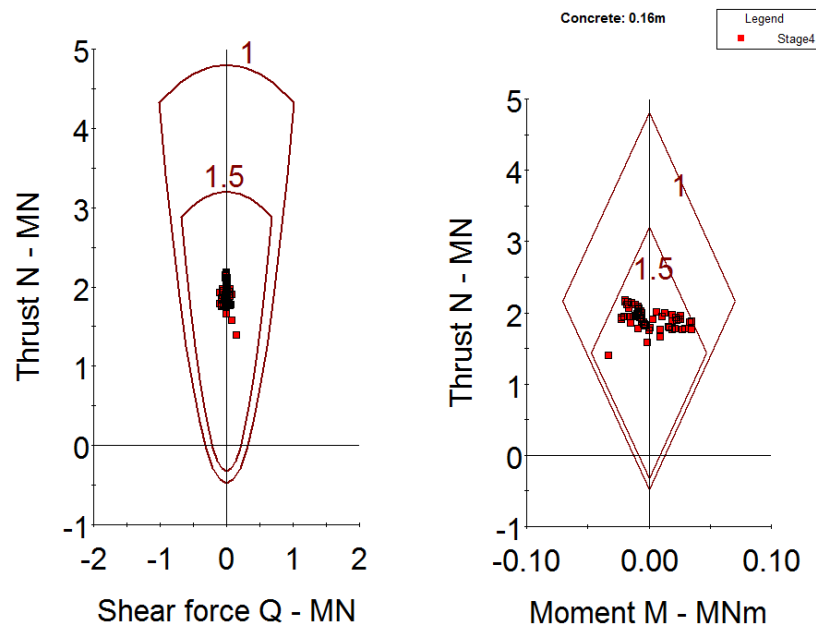


Figure 6-20 Plastic zone and total displacement with support (Rock Class IV)



Support Element: plastic fiber shotcrete

Figure 6-21 Rock dowel axis stress (Class IV)

Notice that all data points fall within the factor of safety=1.5 envelope on all plots.

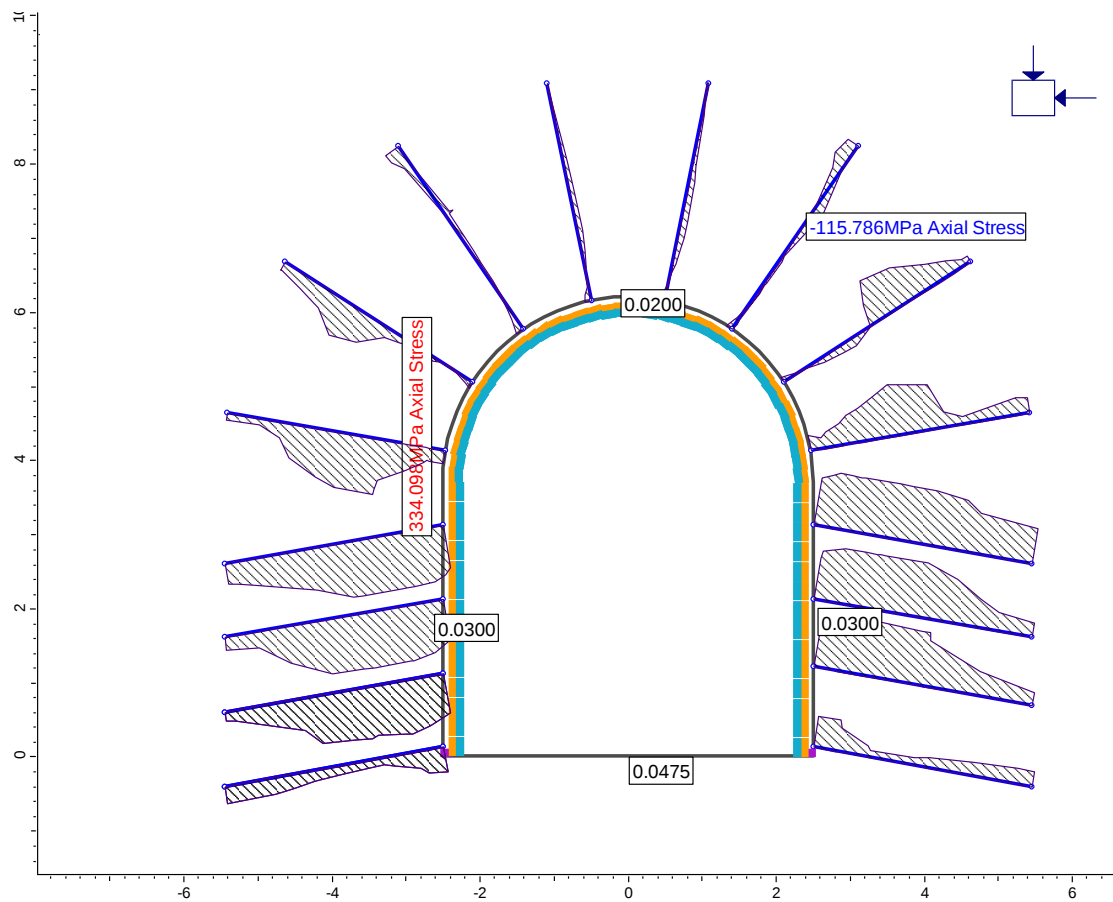


Figure 6-22 Bearing capacity of shotcrete and steel support (Rock Class IV)

Notice that the tensile stress and compressive stress is greater than the allowable tensile strength and compressive strength of rock dowel.

6.6 Rock class IV (Max. buried depth 150m)

For rock class IV without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-23.

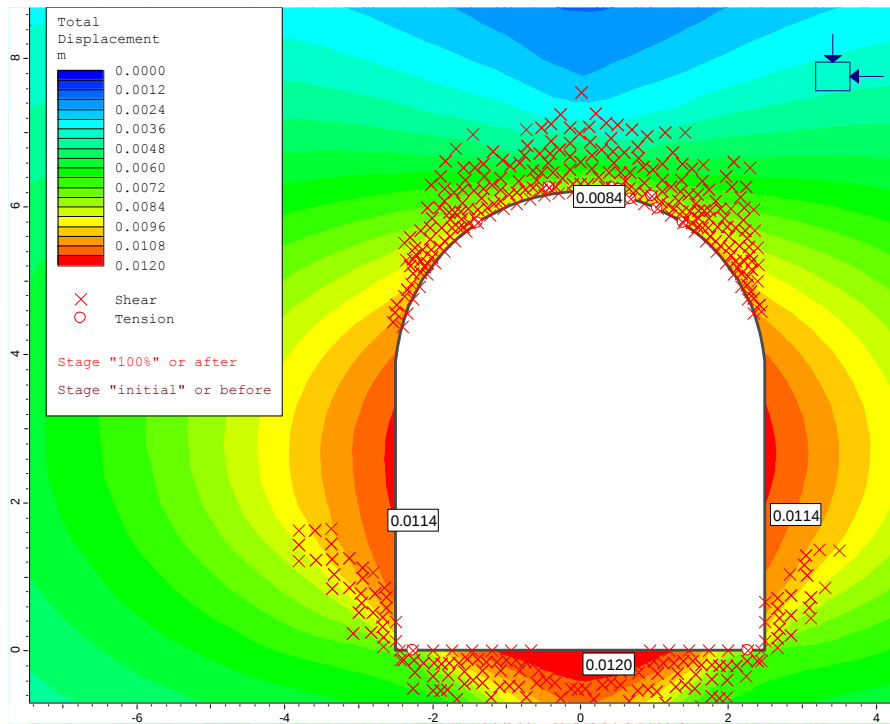


Figure 6-23 Plastic zone and total displacement (Rock Class IV)

The plastic zone and total displacement with support is shown in Figure 6-24, and the bearing capacity of shotcrete is shown in Figure 6-25.

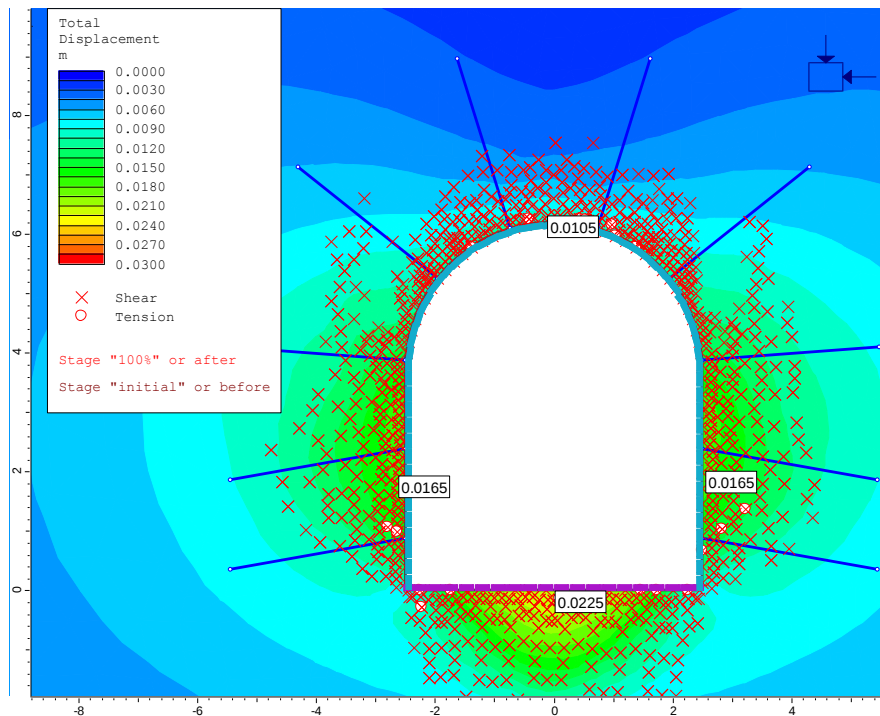


Figure 6-24 Plastic zone and total displacement with support (Rock Class IV)

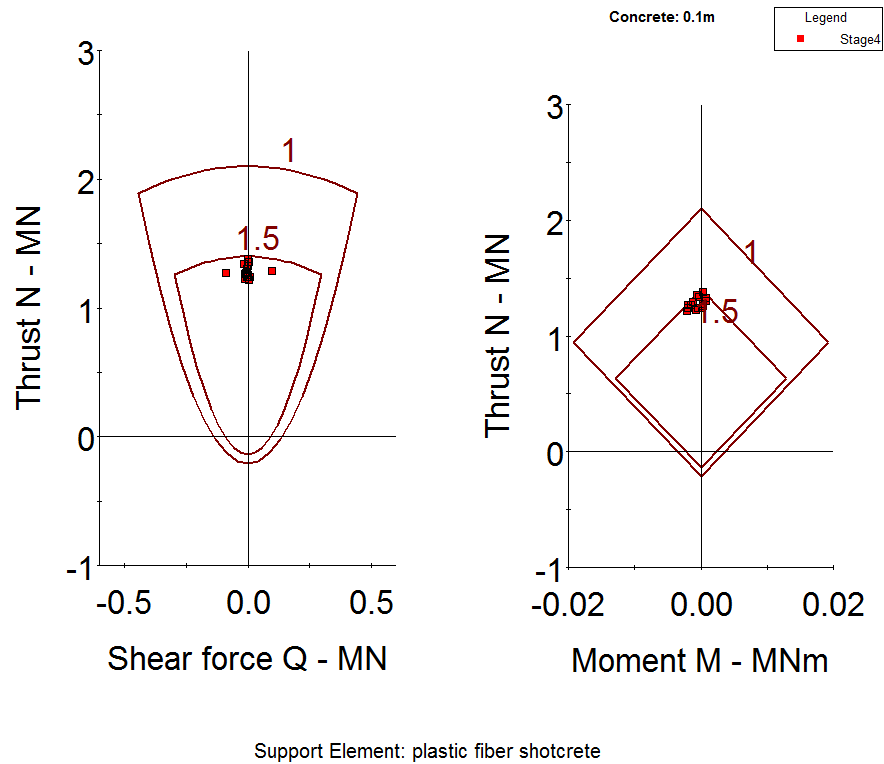


Figure 6-25 Bearing capacity of shotcrete (Rock Class IV)

Notice that lots of the data points fall out of the factor of safety=1.5 envelope on all plots.

Some support system is considered:

- (1) The shotcrete thickness is increased to 0.14m,
- (2) The shotcrete strength is increased to 30MPa,

The plastic zone and total displacement with support is shown in Figure 6-26, and the bearing capacity of shotcrete is shown in Figure 6-27, and the axis stress of rock dowel is shown in Figure 6-28.

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

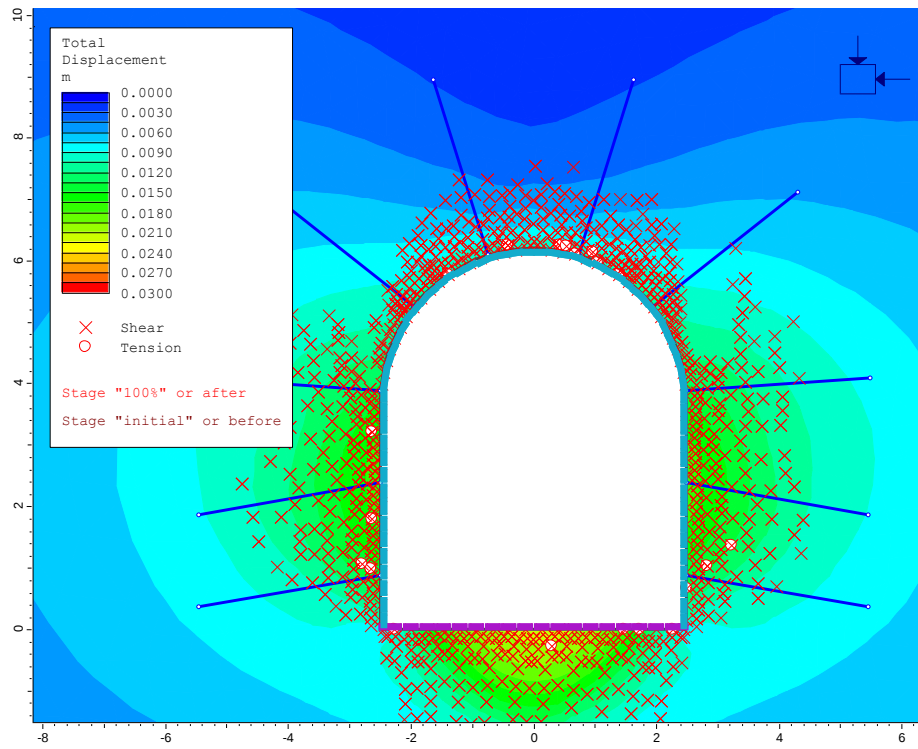
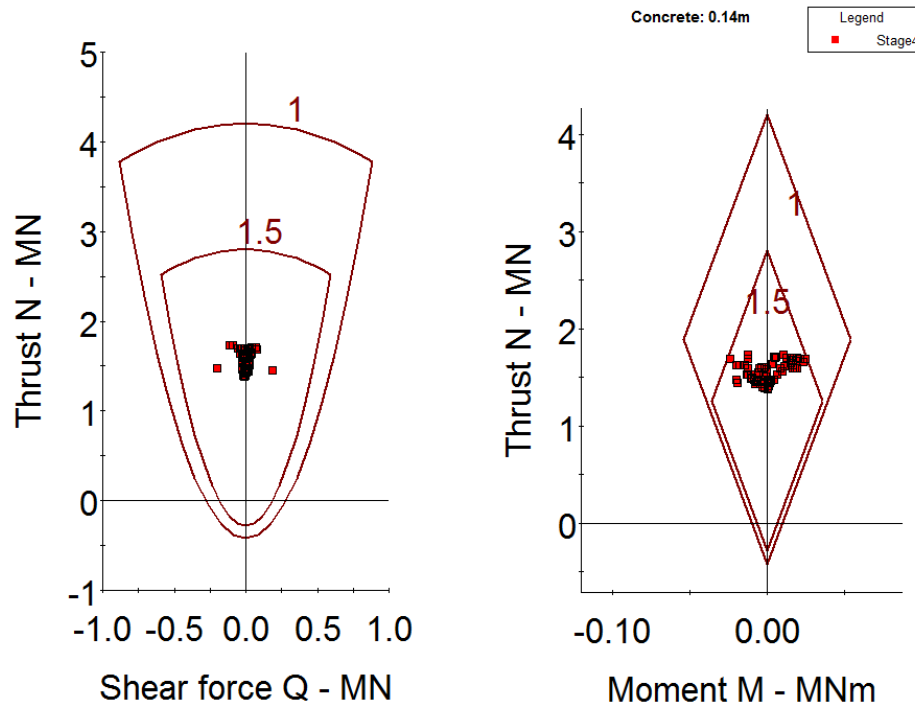


Figure 6-26 Plastic zone and total displacement with support (Rock Class IV)



Support Element: plastic fiber shotcrete

Figure 6-27 Rock dowel axis stress (Class IV)

Notice that all data points fall within the factor of safety=1.5 envelope on all plots.

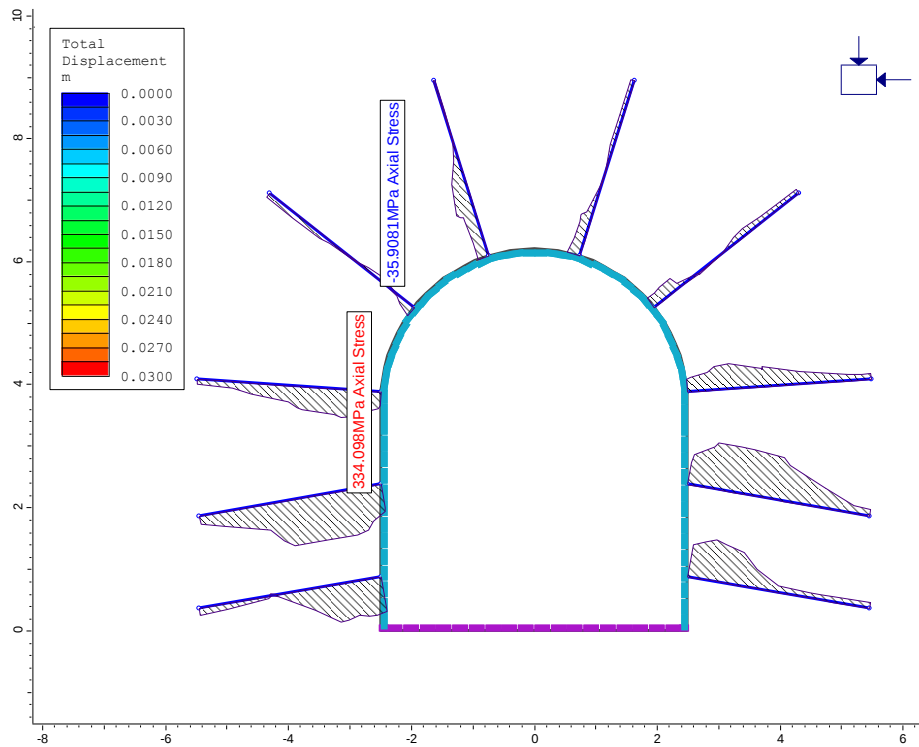


Figure 6-28 Bearing capacity of shotcrete and steel support (Rock Class IV)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel.

6.7 Rock class IV (Max. buried depth 100m)

For rock class IV without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-29.

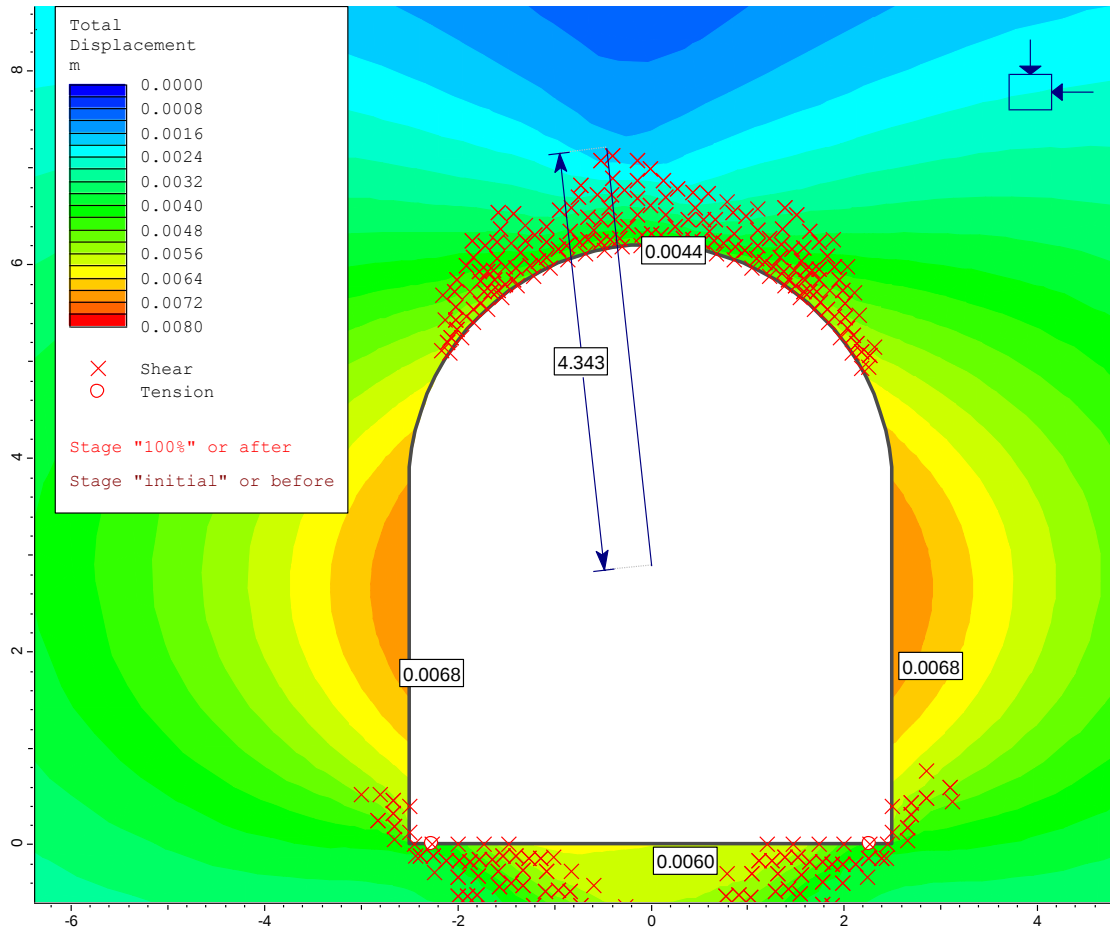


Figure 6-29 Plastic zone and total displacement (Rock Class IV)

The plastic zone and total displacement with support is shown in Figure 6-30, and the bearing capacity of shotcrete is shown in Figure 6-31, and the axis stress of rock dowel is shown in Figure 6-32.

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

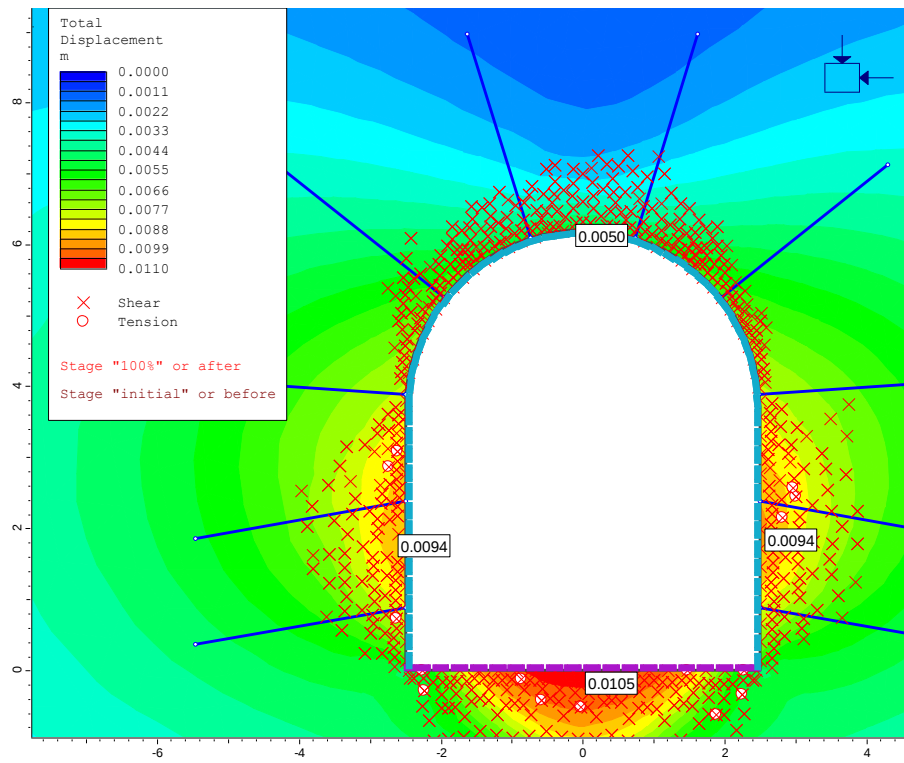
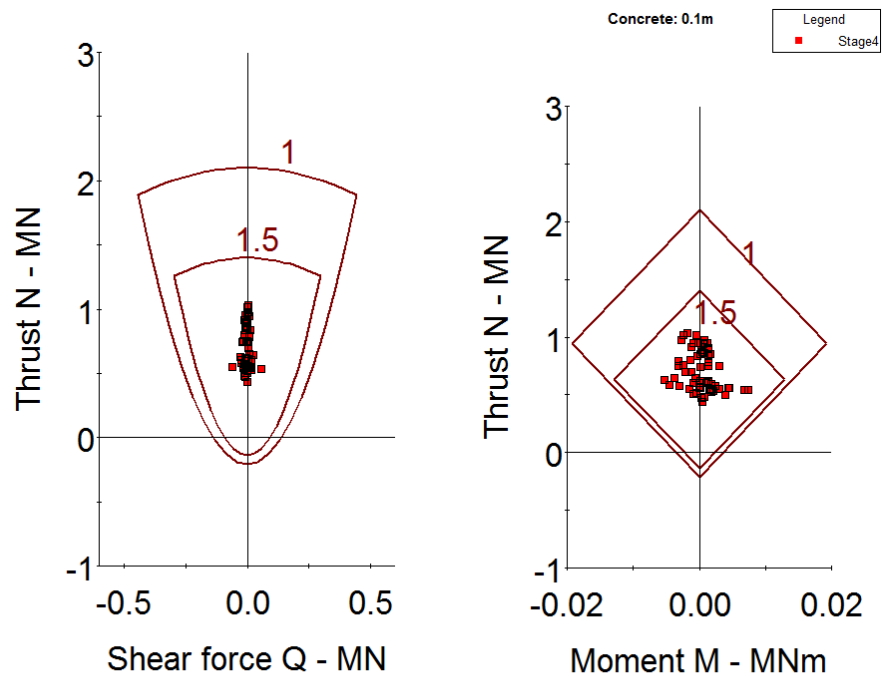


Figure 6-30 Plastic zone and total displacement with support (Rock Class IV)



Support Element: plastic fiber shotcrete

Figure 6-31 Bearing capacity of shotcrete of Ventilation tunnel (Rock Class IV)

Notice that all data points fall within the factor of safety=1.5 envelope on all plots.

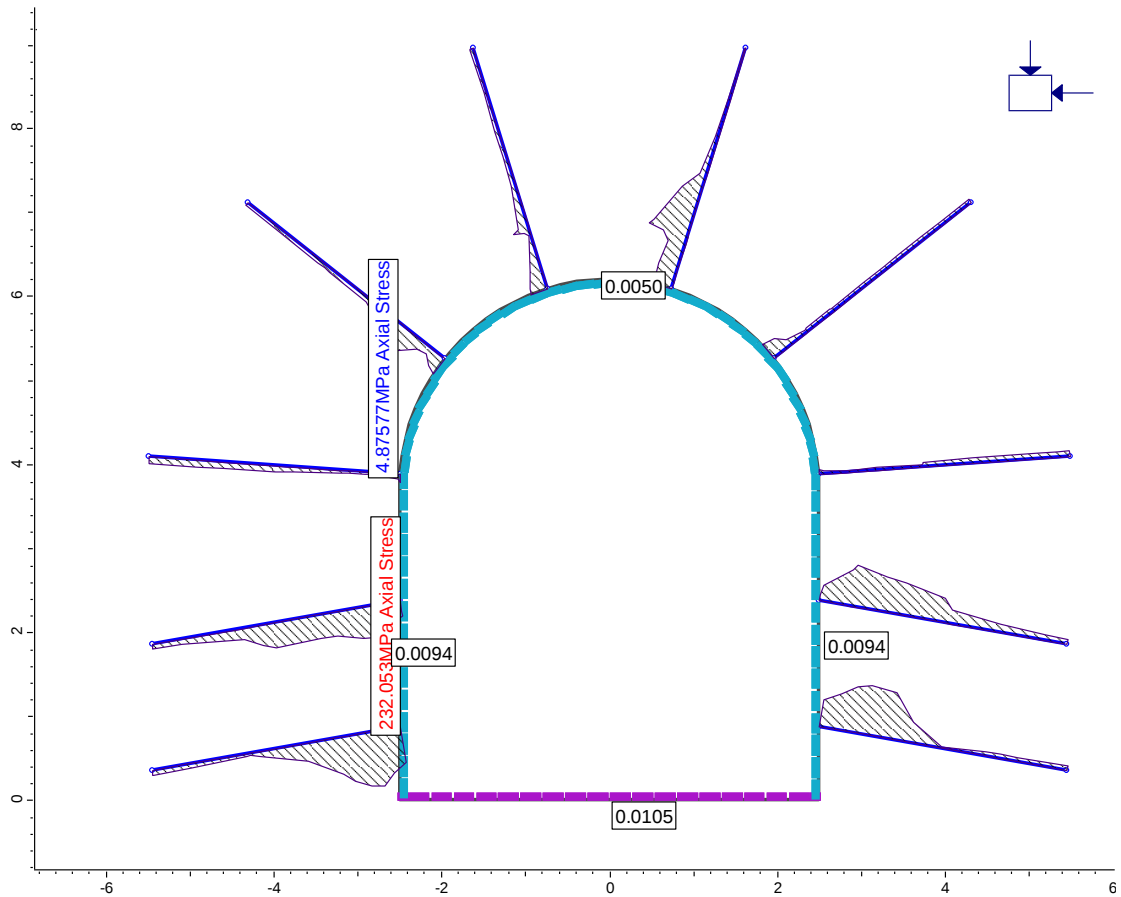


Figure 6-32 Rock dowel axis stress (Rock Class IV)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel.

6.8 Rock class IV (Max. buried depth 55m)

For rock class IV without support, adopting the parameters listed in Section 3, and the calculated displacement and plastic zone are shown in the Figure 6-33.

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

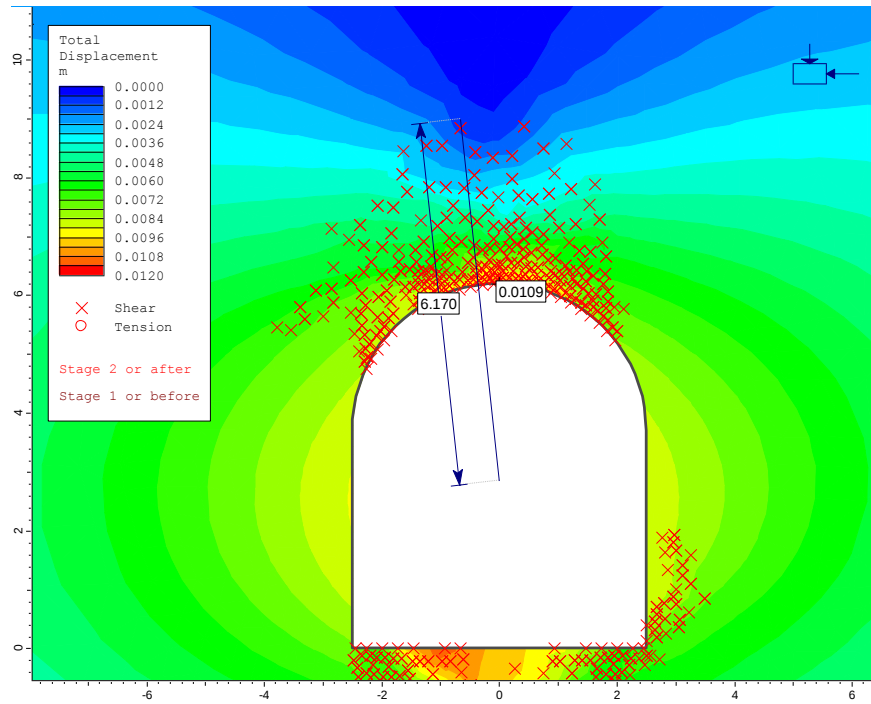


Figure 6-33 Plastic zone and total displacement (Rock Class IV)

The plastic zone and total displacement with support is shown in Figure 6-34, and the bearing capacity of shotcrete is shown in Figure 6-35, and the axis stress of rock dowel is shown in Figure 6-36.

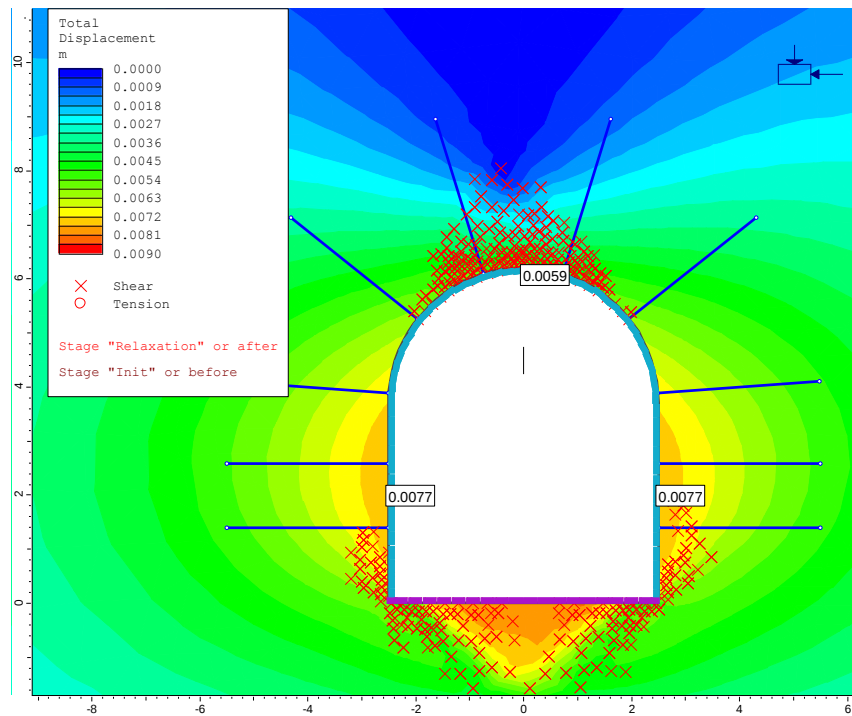


Figure 6-34 Plastic zone and total displacement with support (Rock Class IV)

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

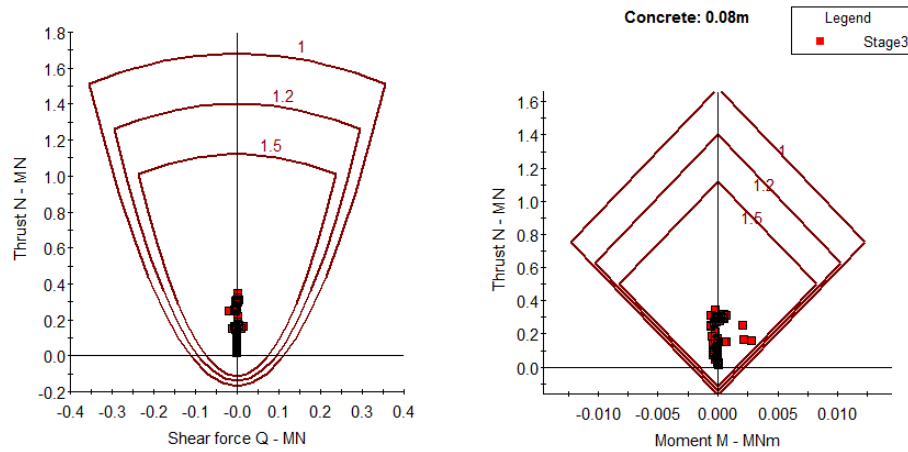


Figure 6-35 Bearing capacity of shotcrete (Rock Class IV)

Notice that all the data points fall within the factor of safety=1.5 envelope, on all plots. This means that the support system chosen has a factor of safety greater than 1.5.

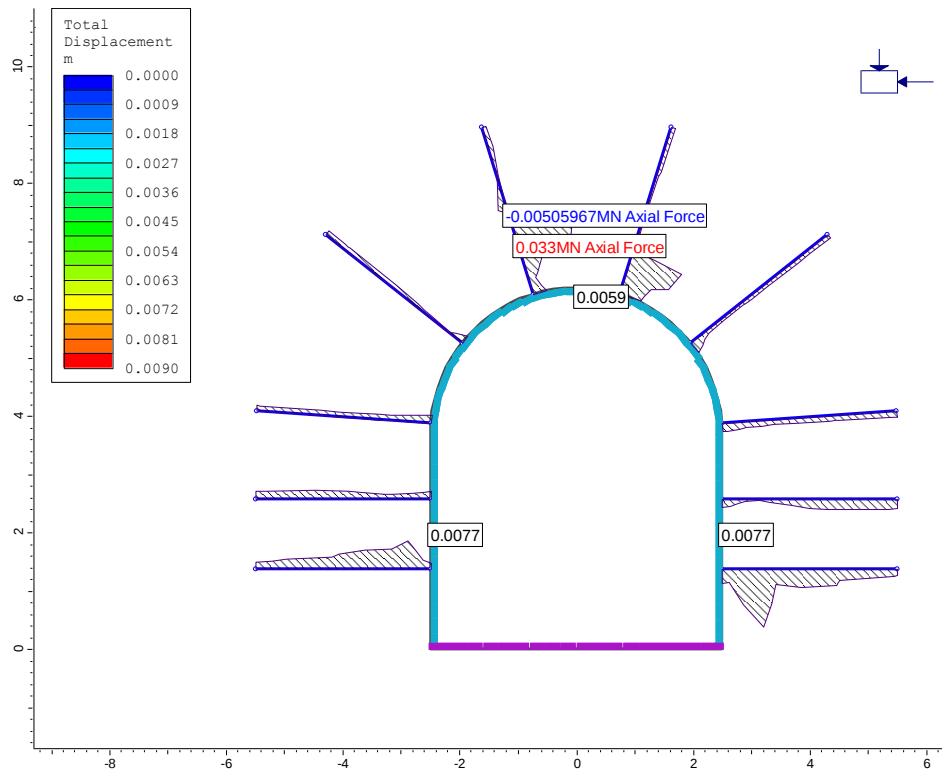


Figure 6-36 Rock dowel axis stress (Class IV)

Notice that the tensile stress and compressive stress is less than the allowable tensile strength compressive strength of rock dowel.

7 Wedge Analysis

7.1 Discontinuity Input Data

According to the site investigation, there are three group joints may distribute in the investigation tunnel, as is shown in Table 7-1. The stereographic projection of these joints in rock mass is shown in Figure 7-1. The Mechanical parameter of joints is shown in Table 7-2.

Table 7-1 Occurrence of joints in investigation tunnel

Joint NO.	Dip Direction	Dip	Tunnel Direction
J1(foliation)	340 °	20 °	N3 E
J2	235 °	70 °	
J3	25 °	60 °	

Table 7-2 Mechanical parameter of joints in the investigation tunnel

JONIT TYPE	JRC	JCS	C	Φ
		(MPa)	(MPa)	(°)
Foliation(J1)	6	70	0.20	35.0
lithoclasts cemented (J2、J3)	8	50	0.15	28.8

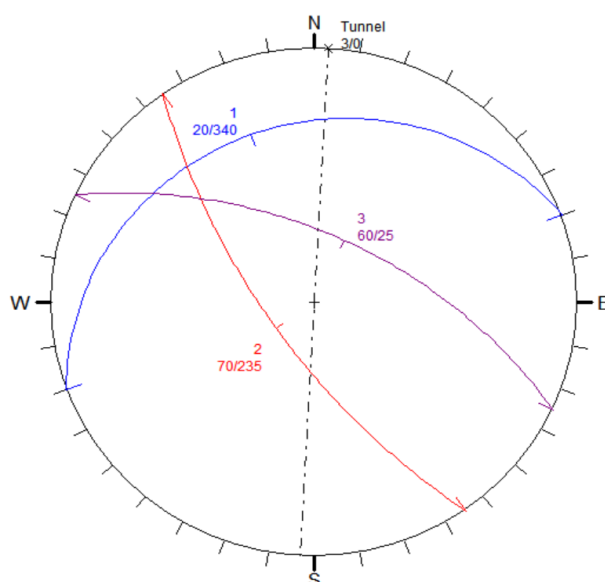


Figure 7-1 Stereographic projection of the joints in the investigation tunnel

7.2 Wedge Stability Analysis

According to the wedge stability analysis, 4 potential wedge may occur in the excavation periods, which are shown in Figure 7-2~Figure 7-5.

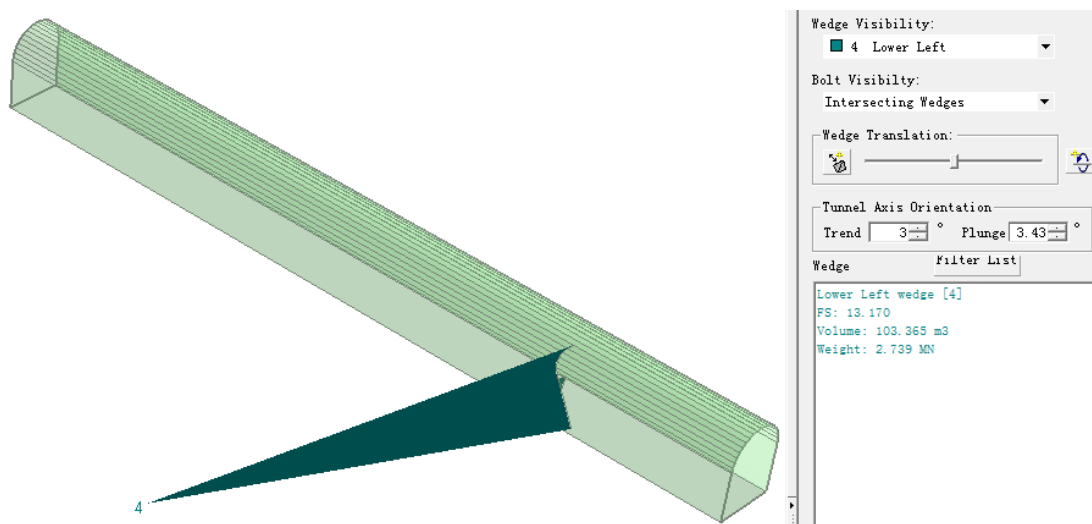


Figure 7-2 Potential wedge on the lower left side

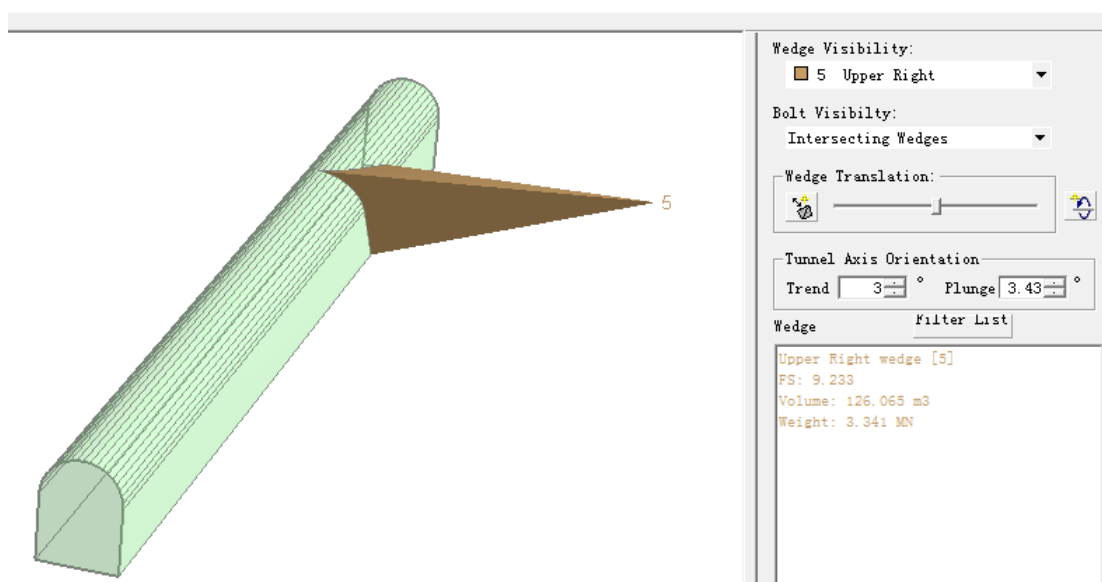


Figure 7-3 Potential wedge on the upper right side

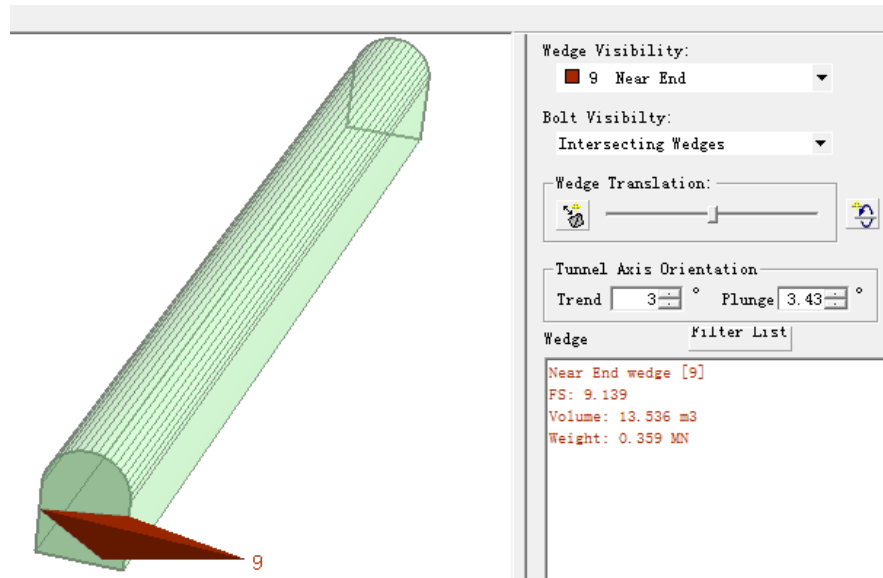


Figure 7-4 Potential wedge near end

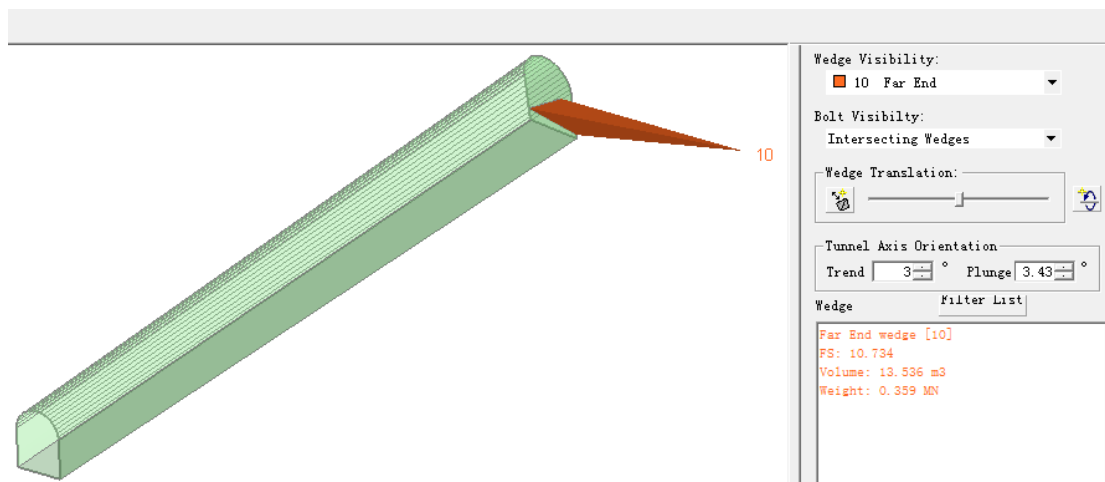


Figure 7-5 Potential wedge far end

It could be drawn from the calculation results that the minimum safety factor of potential wedges without supports in investigation tunnel is 9.139 which is bigger than the minimum safety factor of 2.0.

8 Conclusions and Recommendations

8.1 Conclusions

As per the calculation for investigation tunnel above, it can be concluded as follows:

- (1) For rock class I, It can be seen that the maximum displacement is less than 0.001m, the systematic support is not required. In the actual excavation process, spot shotcrete can be carried out according to the exposed rock or OE's instruction.
- (2) For rock class II, the initial proposed supports meets the requirement of tunnel stability.
- (3) For rock class III, while the maximum buried depth is no greater than 200m, the initial proposed supports meets the requirement of tunnel stability; when the maximum buried depth is greater than 200m, the thickness of shotcrete should be improved to 120mm.
- (4) For rock class IV, while the maximum buried depth is no greater than 100m, the initial proposed supports meets the requirement of tunnel stability; while the maximum buried depth is greater than 100m and less than 150m, the thickness of shotcrete should be improved to 140mm and the strength of shotcrete should be improved to 30MPa; while the maximum buried depth is greater than 150m and less than 200m, more measures should be provided, e.g.: The shotcrete thickness is increased to 0.16m, the shotcrete strength is increased to 30MPa, the spacing of Steel support and rock dowel is increased to 1m.
- (5) For rock class IV, only the buried depth below 200m is considered, and special research is conducted when the buried depth exceeds 200m.
- (6) For the rock class V, after improving the integrity and firmness of surrounding rock through grouting, the same support scheme as the rock class IV can be adopted.
- (7) The shotcrete strength used here is the minimum requirements meeting stability design.
- (8) For wedge analysis, the minimum safety factor of potential wedges without supports in investigation tunnel is bigger than the minimum safety factor. However, the drainage system in construction periods is extremely important in the stability calculation of wedges, it should be cause attention in the excavation process.

8.2 Recommendations

According to the calculation above, the recommended supports for each rock type are summarized in the Table 8-1.

Table 8-1 Recommended supports for each rock type

Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse

Item	Unit	Initial proposed supports							
		I	II	III		IV			
Max. buried depth	m	305	305	305	200	200	150	100	55
Shotcrete thickness	mm	Spot	50	120	80	160	140	100	100
Shotcrete strength	MPa	21	21	21	21	30	30	21	21
Rock dowel length	m	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Rock dowel spacing within each row	m	spot	spot	2.0	2.0	1	1	1.5	1.5
Rock dowel row spacing	m	spot	spot	2.0	2.0	1	1	1.5	1.5
Steel support/Lattice girder spacing	m					1			
Stability		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes